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Feature Analyses
of
Relational Database
Management Systems

by the

ANSI/X3/SPARC DBS-SG

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chaired by

Michael L. Brodie
and
Joachim W. Schmidt

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1. Introduction

In May 1979, the Relational Database Task Group (RTG) was chartered to investigate the justifiability of proposing to ANSI/X3 that a project be initiated to develop a relational standard. Having concluded that such a proposal is justified, the RTG drafted a document (an SD-3) entitled "Proposal for Standard Interfaces to Relational Database Management Systems," to be submitted to ANSI/X3. The RTG proposes that the functionality of the interfaces to Relational Database Management Systems (RDBMS) be standardized.

The work of the RTG that led to the proposal consisted of three tasks:

1. Identifying the fundamental concepts of the Relational Data Model (RDM).

2. Characterizing the features of existing and potential RDBMSs in order to determine the interface functions.

3. Investigating the role of the RDM and RDBMS in a DBMS architectural framework (such as the ANSI/X3/SPARC prototypical architecture), and in a coherent family of DBMS standards.

The current document reports specific results gained in the second task that involved a detailed analysis of twelve DBMSs. Each system was evaluated using the same "catalogue" of features. Section 2 discusses the development of the catalogue. The catalogue itself is given in Section 3. The application of the catalogue to perform the analyses is discussed in Section 4. Finally, the twelve feature analyses are given in Section 6. An additional feature analysis that was submitted too late for consideration by the RTG is included.

The final results of the RTG's work are given in the "Final Report of the ANSI/X3/SPARC DBS-SG Relational Data-

base Task Group".* edited by Michael L. Brodie and Joachim W. Schmidt, dated September 1981. In particular, Chapter 3, entitled "Analysis of Relational Systems", compares the features of the twelve systems based on the feature analyses given in this document.

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*This document, numbered SPARC-81-690, soon will be available through the National Technical Information Service (NTIS) of the U.S. Government.

2. Development of the Feature Catalogue

In order to "identify or establish aspects of the RDM and RDBMSs that might be appropriate for standards development", the RTG developed a "Feature Catalogue" of Relational Concepts, Languages, and Systems". The catalogue was intended as an abstract (implementation independent) characterization of RDM and RDBMS concepts. It was used as a basis for a detailed feature analysis of a number of existing DBMSs that were claimed to support aspects of the RDM. Due to limited resources, only a few DBMSs could be examined.

A feature catalogue* was developed to guide the analyses of selected relational database management systems. The purpose of using a feature catalogue was to ensure that all systems were described in the same format and that all features of interest to the RTG were considered in the analyses.

The purpose of the analyses was to gain insight into:

1. RDM:

   a. essential or core concepts, and
   b. additional concepts or extensions.

2. Systems issues concerning the support and use of the RDM:

   a. aspects closely tied to the model, such as the design of interfaces, and
   b. general system features, e.g., locking, concurrency, security, access control.

Nonrelational features were included in the feature catalogue for two reasons:

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*"RTG 80-81 Feature Catalogue of Relational Concepts, Languages, and Systems" (Section 3 of this report) and "RTG 80-90 Notes on Completing an RTG Feature Analysis (Section 4.2 of this report)."

1. The analyses were required to decide whether a particular common DBMS feature was related to the RDM. One objective of performing the analyses was to determine what DBMS features were dependent on the RDM.

2. One reason for supporting the development of a relational standard is the task group's finding that there is a significant number of complete, useable DBMSs supporting aspects of the RDM. If the only implementations of the RDMs were research vehicles, a standard might be premature. Therefore it was important to determine the full capabilities of the systems being analyzed.

The intent of the task group was to categorize the features on the basis of the analyses according to the following taxonomy [ARTH80]:

1. Features that appear in every system that are claimed to be relational.

2. Features that do not appear in every system but are rapidly being added to many systems.

3. Features that are felt to be important but do not yet appear except in the literature or in research systems.

4. Features that have been in some systems for some time but do not appear to be spreading to other systems.

5. Features that distinguish the relational approach from other approaches.

Features in categories 1 and 2 would form the basis for a standard, while features from categories 3 and 4 could be used as a basis for future developments. Features in category 5 would be used to exclude nonrelational systems.

Besides supporting a standard, the analyses based on the feature catalogue are expected to be useful in the following ways:

1. To relate specific knowledge of the state-of-the-art to research and development results.

2. To demonstrate the amount and nature of work in implementations, applications, and literature.

3. To determine to what extent RDM concepts are constrained by implementation concerns.

The feature catalogue on which the analyses are based is the third version developed by the RTG. The initial version was based on the Generalized DBMS Survey completed by the CODASYL System Committee in 1969. This version was tested by asking members to analyze selected systems. The catalogue was found to be incomplete because some hierarchical DBMSs could be described as "relational" following the catalogue. A second version of the catalogue placed more weight on purely relational features, but it was too detailed for our purposes. In the third version of the feature catalogue this problem is not completely solved. However, the overall organization of information is clear and easy to follow.

The relative importance of relational concepts, languages, and systems is reflected in the structure of the catalogue. First, RDM concepts are considered, followed by associated functional capabilities and ending with DBMS features. Within the categories of functional capabilities, query and manipulation are considered before definition, generation, and administration. This ordering indicates the distinction between RDM concepts and RDBMS features in response to the RTG charter.

3. The Feature Catalogue

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FEATURE CATALOGUE OF

RELATIONAL

CONCEPTS, LANGUAGES and SYSTEMS

May 1980

Working Paper RTG-80-81

of the

Relational Database Task Group

of

ANSI/X3/SPARC - Database System Study Group

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Please refer to RTG-80-90 for comments on completing a feature analysis based on this feature catalogue.

by

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and

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1. Introduction

1.1 Identification

Give the name of the system (and version where applicable) together with some information about its origin.

1.2 Status

1.2.1 System

Give the development status of the system together with the appropriate release dates. Planned extensions and their proposed dates can be identified. More details can be given later in the appropriate sections; however, the features should be clearly marked as proposals.

1.2.2 Applications

Describe briefly the class of applications for which the system is intended and those applications for which it may be less well suited. Characterize the limits placed by the system applications, e.g., total size. List the know applications; these may be described in more detail, in section 8.0.

1.3 System Background

Describe briefly how the system came into being, what (if any) family of similar systems it belongs to and on which systems (if any) it is based.

1.4 Overall Philosophy

If possible, give a statement of overall philosophy including motivation for designing and developing the system, objectives for the system, major contributions and features unique to or emphasized by the system, and the design rationale for meeting these goals.

1.5 Essentially Relational Characteristics

Recently (TODS Vol. 4, No. 4, Dec. 1979), Codd wrote that for a system to be considered fully relational it would have to support:

(i) structural aspects of the relational model;

(ii) the insert, update, and delete rules; and

(iii) a data sublanguage at least as powerful as the relational algebra, even if all facilities the language may have for iterative loops and recursion were deleted from that language.

(For further details see the referenced paper.)

He also stated that if the data sublanguage was not supported, then the system might be considered semirelational.

There may be varying degrees of semirelational systems, depending on the level of the data structures and languages and on the restrictions placed on relational operations.

The level of the data sublanguage is significant. The relational algebra operators, i.e., extended cartesian product, union, intersection, difference, projection, selection, restriction, join, and possibly division, must be atomic. These operations could be implemented in assembler which is not relational in nature.

A DBMS which places restrictions on the use of the relational algebra operations such as join (i.e., more restrictions on join than union compatibility of join attributes) may be considered as semirelational or even not relational in nature. The following are examples of restrictions which reduce the power of the join operation:

(i) cycles are not permitted. In the relational approach, any series of joins including those that result in a cycle can be expressed. Some database models do not permit cyclic relationships.

(ii) a relation cannot be joined with itself. Some database models do not permit an entity (e.g., a record type) to be related to itself.

(iii) only one join is permitted between two relations. In the relational model, a join is permitted between two relations as long as the join attributes are union compatible. There is no other restriction, such as the number of such pairs or join attributes between relations.

(iv) relations must be connected by joins. The relational model permits relations to exist independently of any other relations. DBMSs which are based on explicit links make few provisions for this case.

The following advantages have been claimed for the relational database model and used to distinguish relational systems from those that are not relational in nature:

1. no access path dependencies such as information bearing links, e.g., a relation can exist independently of any other relations;
2. no order dependencies among tuples;
3. no index dependencies for database access;
4. no insert, update or delete dependencies such as storage and removal classes, e.g., unconditional delete of dependent tuples when the parent tuple is deleted;
5. high-level, non-procedural, set-oriented qualification primitives (see Section 3.1);

6. the ability to derive and maintain dynamically a user view (i.e., derived relation) from one or more existing relations;
7. the ability to add and delete semantic integrity constraints during the lifetime of the application.

[Please make suggestions for extending this list. See also Section 7.0 for advantages of relation approach.]

If the system or language under consideration does not possess one or more of the advantages then it may not be relational in nature.

This section is intended to distinguish between systems that are fully relational, semirelational, and those that are not relational in nature. This distinction raises the question whether there is an essential difference between, for instance, the relational, hierarchic, and network database models. If there is no essential difference it would seem unlikely that a relational standard be justifiable.

Based on the above information (and on additional proposals by you) classify the system or language being considered as fully relational, semirelational, or not relational in nature.

1.6 Interfaces

A database management system presents, through one or more interfaces or languages, some of the following capabilities (after each capability is a list of sections in the feature catalogue in which the capability is described):

(1)	Database Schema Definition	4.1
(2)	Query Language	3.1,3.2,3.4
(3)	Database Altering	3.1,3.3,3.4
(4)	Constraint Definition	2,4
(5)	Database Generation and Regeneration	4.2,4.4
(6)	Database Schema Redefinition and Renaming	4.3
(7)	Report Generation	3.1,3.2,3.4
(8)	Data Entry	
(9)	Security Definition, Monitoring and Control	6.1
(10)	Database Control (utilities): load, dump backup, restore, recovery, monitoring, etc.	6.2,3.2,3, 3.4.7
(11)	Definition of Storage Structure, Indexes,	

and Access Paths
(12) Database Dictionary (database design, dictionary query, etc). 3.2.2,4.5
(13) Special Purpose Language

For the system under consideration, identify its interfaces or languages. Briefly characterize each language in terms of its capabilities. A more detailed description of the interfaces is given in Section 5.

1.7 Documentation

Give a bibliographic list of documentation available on the system (especially those documents used for the feature analysis). Also, give a list of technical papers that discuss the system.

1.8 General System Description

Briefly describe any important characteristics of an introductory nature, perhaps unique to the system, that have not yet been described in the introduction.

2. Database Constituents

A database may be perceived as consisting of a number of constituents. Each constituent may be viewed as a structure, together with a fixed set of operators, with both the structure and operations restricted by some constraints.

There are a number of distinct perceptions of relational databases. A relation may be perceived, e.g., as: a set of tuples, array (table) of tuples (rows), an n-ary predicate, a n-ary function, and as a file. A system may present only one such perception at all interfaces, different but distinct perceptions in different interfaces (e.g., set-oriented queries, predicate-oriented queries, functional queries, arrays for programming language interfaces, and files for the DBS interface) or a mixture of perceptions (e.g., both set and array oriented operations).

The perceptions presented should be characterized. If more than one perception is presented and each has different characteristics (i.e., operational semantics), they should be treated distinctly (i.e., apply section 2 to each perception).

2.1 General Description

List the constituents of a database and their relationship; e.g., the feature catalogue assumes the following constituents. A particular system may have more constituents, or less.

The constituents of a System N database are: DB(=database), R(=relation), V(=view), T(=tuple), A(=attribute), D(=domain).

These constituents are related as follows: A relational DB consists of R's of possibly different type. An R consists of T's of identical type. A V is an R derived from one or more R's by means of qualification operations.

A T consists of A values of possibly different type. A's are defined in terms of a D. Finally, a D is a user defined data type.

Note that DB, R, V, T, A, D are the system's terms which should be used but equated to the feature catalogue terms using "(=F.C. term)" where the terms differ. For quick reference a term translation table should be given in this section.

[2.X Constituent

For each constituent in Section 2, describe the structure and constraints in detail. Operations should be listed with a brief description of their effect (semantics). A more detailed description of operations is given in Sections 3 and 4.]

2.2 Database

2.2.1 Database Structure

Describe a database structure at the schema level (type level) at the instance level (value level). Describe the mechanism for naming (identifying) a database. What is the role of relations and views in database structuring?

2.2.2 Database Operations

List the operations for defining, generating, and manipulating a database structure.

2.2.3 Database Constraints

Characterize the constraints (e.g., global assertions) that can be defined on a database structure and its operations. How are these constraints maintained over a

database and how are violations handled?

2.2.4 Additional Database Properties

Describe properties about a database not given in the above sections.

2.3 Relation

2.3.1 Relation Structure

Give the system's definition of a relation. Keep in mind that the schema level notion of a relation may differ from the instance level notion. What is the predominant perception of a relation (i.e., table of rows and columns, set of tuples, entities over which functions or predicates can be evaluated). Describe the naming (identification) mechanism for relations. What is the role of tuples and attributes in relation structuring? Are duplicate tuples allowed? Is attribute order significant? Can alias names be defined?

2.3.2 Relation Operations

List the operations for defining and manipulating a relation structure. Is the design of the operations oriented more toward formal rigor (relation or set algebra, applied predicate calculus, mappings, etc.), procedurality and control (variables, operators, expressions, control variables, control statements, etc.), end-user convenience, or semantic richness? What is the role of tuples and attributes in these operations, e.g., what are the compatibility requirements for operands in these operations?

2.3.3 Relation Constraints

Characterize the constraints (e.g., functional dependencies, keys, predicates, joining restrictions) that can be defined on a relation structure and its operations. Give the system's definition of key and its roll as a relation constraints. Are constraints on relations perceived as query modifiers, as definitions of exception or trigger-raising conditions? Or are they considered to be like datatype definitions leading to type violations? How do constraints interact with the database manipulation facilities? Are there any query facilities based on the definition of constraints (e.g., on relation keys)? What are the constraints imposed on relations through attributes? How are constraint violations handled?

2.3.4 Additional Properties of Relations

Are there any additional properties of relations? Can a short statement be made about the use of relations in "real world" modeling?

2.4 Views

2.4.1 View Structure

Give the systems definition of a view. The schema level and instance level notions of view may differ. How does a view structure differ from a relation structure? Can views be dynamic and static? How are views derived? What is the role of (base) relations and views in view structuring? Describe the naming mechanism for views. Are keys definable for views or are they inherited from the (base) relations?

2.4.2 View Operations

List the operations for defining and manipulating views. Are view definition operations a subset of the qualification (3.1) operations? Are view manipulation operations a subset of the relation operations? Are there operations and views that are not available on relations? Under what conditions can relation operations be applied to views?

2.4.3 View Constraints

Characterize the constraints (e.g., access control, subsetting, logical restrictions, general assertions) that can be defined using views. Compare view constraints with relation constraints emphasizing those unique to and specialized for views. How are view constraint violations handled?

2.4.4 Additional Properties of Views

Are there any additional properties of views? Are views intended to be treated or seen as different from relations? Characterize if applicable dynamic and static views (snapshots). What is the intended role of views for modeling, querying, assessing parts of the database? Can a brief statement be made on the use of view in conceptual modeling.

2.5 Tuple

2.5.1 Tuple Structure

Give the system's definition of a tuple. Describe a tuple structure (i.e., record type) and a tuple value (i.e., record instance). In some systems a tuple may be

defined implicitly when a relation is defined. What is the role of attributes and domains in tuple structuring? Are keys definable at the tuple or relation level? Describe the mechanisms for unique tuple qualification, e.g., based on unique key values.

2.5.2 Tuple Operations

List the operations for defining and manipulating tuples. Are there explicit or implicit tuple-oriented operations (e.g., existence test, equality test, read, write, replace) or control structures (e.g., FOR EACH e in EMPL)?

2.5.3 Tuple Constraints

Characterize the constraints (e.g., uniqueness, order, assertions, inter-attribute restrictions) that can be defined on tuples. How are tuple constraint violations handled?

2.5.4 Additional Properties of Tuples

Are there any additional properties of tuples? Is there an exclusive tuple-oriented interface? Are tuples addressed explicitly or implicitly? Are tuples treated as elements of a set? Are tuples treated as entries in an array? Are tuples treated as values in the domain of an n-ary function or predicate? Can a brief statement be made on the use of tuples in conceptual modeling?

2.6 Attribute

2.6.1 Attribute Structure

Give the system's definition of an attribute. The schema and instance level notions of attribute may differ. Is the concept of an attribute supported independently of domains or primary data types? What is the role of domains and primary date types in attribute structuring? How do attributes differ from domains? Describe the naming mechanism for attributes. Can alias names be defined? Are there any distinguished attribute values (e.g., null, unknown, undefined, etc.)?

List the operations for defining and manipulating attributes (e.g., the relational comparison operators <, <, =, >, > / ; arithmetic operations +, -, -, *; aggregation functions SUM, COUNT, MAX, MIN, etc.). Give the compatibility and coercion rules for these operators. Do attributes have different compatibility rules than the underlying domains or primary data types? Can attribute operations be defined or are they inherited for the underlying domains?

2.6.2 Attribute Operations

2.6.3 Attribute Constraints

Characterize the constraints (e.g., assertions, value restrictions, operation restrictions) that can be defined on attributes. How are attribute constraint violations handled? Distinguish attribute and domain constraints and emphasize constraints unique to attributes.

2.6.4 Additional Properties of Attributes

Are there any additional properties of attributes? Are attributes supported implicitly or explicitly? Can a brief statement be made on the use of attributes in conceptual modeling?

2.7 Domain

2.7.1 Domain Structure

Give the system's definition of domain. Is a domain a set of fundamental objects or entities, a set of values, part of a type definition, etc. Which kinds of domain exist (predefined) or can be defined (integer-based, string-based, etc.)? Is an order defined on domains? Are there any distinguished domain values (e.g., null, unknown, undefined, etc.)? What is the role of predefined data types in defining domains?

2.7.2 Domain Operations

List the operations that are defined or can be defined together with domains (e.g., tests, comparisons, arithmetic, Boolean). What are the compatibility and coercion rules for this operation? Compare domain and attribute operations and describe those operations associated with domains. Can domain operations be defined or redefined?

2.7.3 Domain Constraints

Characterize the constraints (e.g., value set restrictions, operation restrictions, compatibility of domains, upper and lower limits on value sets, etc.) that exist or that can be defined on domains. How are domain constraint violations handled?

2.7.4 Additional Properties of Domains

Are there any additional properties of domains? Can a brief statement be made on the use of domains in conceptual modeling?

2.8 Additional Database Constituents

Are there any additional constituents in a database in the system being described (e.g., transaction, triggers, data dictionary, procedures, etc.). Describe additional constituents in the same manner as the above constituents. Does the system support assertions? Can assertions be defined and dropped dynamically?

3. Functional Capabilities

The functional or operational capabilities of the system or language(s) under consideration are those facilities used to select and manipulate database constituents. A distinction is made between qualification and operations over selected constituents. Qualification is the selection of a subset of the database for subsequent operations. The selected constituents may be presented to the user, as in the case of queries, or they may be used as arguments in database altering operations.

Functional capabilities are presented to users differently in different systems. All functional capabilities may be provided in one language or in several languages. Please maintain the distinctions given in the feature catalogue and name the interfaces (languages) providing each capability. Some capabilities may be provided through more than one interface, in which case deal with semantic differences here and with syntactic differences in Section 5.0 (do not repeat information).

Different perceptions of relations (see 2.0) may be presented for various functional capabilities. In particular, querying may be done through a set-oriented or n-any predicate (or function-oriented) interface, while updates may be done through an array-oriented interface. Make these distinctions where they are appropriate. See comment j in RTG-80-90 concerning an example.

3.1 Qualification

This section deals with the approach or philosophy taken in the system for selection. Qualification facilities (i.e., selection mechanisms) are used to select database constituents, usually tuples of a relation, for retrieval or altering.

Give a general description of qualification: the nature of the selection mechanism (algebra- or calculus-oriented); the perceptions of relations; the interfaces.

How are the results of qualification perceived by the user? How are exceptional conditions handled?

In the following subsections list and define each qualification mechanism. The operators of the relational algebra and the selection predicates of the calculus should be described in these subsections. An operator is defined by: its arguments, its effects (if any) on its arguments, failure and success conditions, and how it is perceived by the user. What is the role of domains and attributes for each operator? You may have to define or refer to such concepts as tuple variables.

3.1.1 Restriction

List and define the simple conditionals (e.g., $<$, $\leq$, $=$, $\geq$, $\neq$) that can be used to select tuples from a relation. For example, can tuple attributes be compared only to constants or also to the value of other attributes? Specify which types of comparisons are supported for which types of attributes or domains. Are there any restrictions, such as not being able to compare a packed decimal type value to an integer type value. (Give the coercion rules.)

In addition, specify if and how the simple selection conditions can be combined into a more general Boolean expression. The relational algebra operators selection, restriction, and projection should be defined here. Give a small example.

3.1.2 Quantification

If the selection mechanism is calculus-oriented, universal and existential quantification must be supported. What kinds of predicates can be defined? Are predicates explicitly defined as Boolean expressions? e.g., "SOME e IN EMPL (...)", "ALL e IN EMPL (...)". Are they implicit in other operators such as count, group by, divide, subset? Is absolute quantification supported, e.g., "there is at least 3..." "there is at most 10..."? Give small examples.

3.1.3 Set Operations

List and define the supported set operators, i.e., union, intersection, difference, and extended cartesian product. What conditions do the arguments have to fulfill? Describe any other set-oriented operators, e.g., set inclusion. Give small examples.

3.1.4 Joining

List and define each join operation supported, e.g., equi-join, natural join. Describe constraints on the relations to be joined. How many relations can be joined? What conditions on the joining attributes must be met in order to join relations? Must joining attributes have indices or other access paths? Can a relation be joined with itself? Are there any other constraints on joining? (See restrictions on joins in Section 1.5.) Give small examples.

3.1.5 Nesting and Closure

Describe the way in which the qualification facilities interact. Are qualification operations closed, i.e., can the result of a qualification be further qualified? Can simple qualifications be combined (nested) to make more complex qualifications? Are there different (levels of) constructs or languages with which to express more complex queries? How do the qualification facilities interact with other facilities in subsections 3.2, 3.3, and 3.4? Are the qualification facilities "relationally complete"? Give small examples.

3.1.6 Additional Aspects of Qualification

Describe other important qualification facilities not described earlier. For example if relational division is supported, describe it as join was described.

3.2 Retrieval and Presentation

The results of qualification operations can be used to retrieve database constituents and present them in some form of output or report. For each subsection, describe its relationship to qualification described in 3.1 and, if needed, define its own selection mechanism. Give a small example of each facility.

3.2.1 Database Queries

Characterize the facilities for defining queries only in as much as they differ from those for qualification. How are queries expressed? Are there specific facilities for queries that result in a variable number of tuples? Are there specific facilities for 1-element queries (defined by a maximum/minimum condition, or by identity or order of the key values, etc.)? Are there specific facilities for Boolean-valued queries (equivalence to propositional or predicate calculus expressions, membership tests, inclusion tests)? What is the perception of the effect of a query evaluation (a relation, a file, a sequence of actions returning partial results, a Boolean value)? What is the role of domains in queries? Do you consider the query facility as being "relational complete" (i.e., with respect to DSL ALPHA)?

What operations beyond the qualification operations are used in querying, e.g., projection, permute, absolute qualification, user defined functions? How does the query facility relate to the other facilities described in Section 3.

3.2.2 Retrieval of Information About Database Constituents

Describe the facilities that support the query and retrieval of schema information (e.g., database definitions -- what constituents exist, how they are defined, current constraints or assertions over the database). If these facilities depend on authorization over the standard query facilities, do not repeat information in Sections 3.1, 3.2, or 6.1. Describe how these facilities interact with other facilities, e.g., can the result of a schema query be used in a database qualification?

3.2.3 Retrieval of System Performance Data

Describe the facilities for retrieving performance data for an application, e.g., statistical information, performance monitoring information, information about indices, directories, and access paths. If this interface is essentially relational in nature, also refer to it in Section 7. Describe the relationship of this retrieval with respect to qualification described in 3.1.

3.2.4 Report Generation

Describe report generation facilities based on the qualification described in Section 3.1. Pay particular attention to those features that have a relational flavor. Stand-alone report generators not based on Section 3.1 should be listed here and described in detail in Section 5.0.

3.2.5 Constraints and Limitations

Describe any constraints and limitations on the use of retrieval and presentation facilities. These may be related to security, the nature of the interface, the development status of the system, etc. Future developments could be listed here together with proposed release dates.

3.2.6 Additional Aspects of Retrieval and Presentation

Describe any important aspects that were not described in the subsections of 3.2. For example, can a brief statement be made about the philosophy or approach taken to retrieval and presentation.

Can data be retrieved for purposes other than presentation and altering?

3.3 Alteration

The result of a database altering operation is a database state transition; the new state generally depends on the old state of the database and on user-supplied input data.

Depending on the altering facility, the perception of database constituents may vary. The role of relations may be that of a left-hand-side variable in an assignment statement, or a value/result parameter in a function. A relation may also be perceived as a function redefined by the relation altering facility.

The following subsections deal with the basic altering facilities and their relationship. The presentation of the basic concepts should be illustrated by means of examples. The operations described here should refer to but not repeat the information in Section 2.

3.3.1 Insert Facilities

Which of the database constituents can be altered by insertion (relations, views, tuples, attributes, domains)? For each constituent that can be inserted, describe the insert by its effect on the constituents into which insertion is made. Characterize the facility for the definition of insert operations. What is the perception of the user-supplied parameters in the insert operation (are they perceived as relations, as tuples, as input data used by a general facility for the redefinition of relations, etc.)?

What are the roles of tuples, attributes and domains in the insert operation? What is the role of general constraints (e.g., keys, type constraints) and how are constraint violations handled?

Can results of queries be used as parameters in insert operations? Give a small example.

3.3.2 Delete Facilities

Which of the database constituents can be altered by deletion? For each constituent that can be deleted, define the operation by its effect on the constituent from which the first constituent is being deleted. Characterize the facility for the definition of delete operations. What is the perception of the user-supplied parameters in the delete operation (are they perceived as relations, as tuples, as information used by a general facility for the redefinition of relations, etc.)? What is the role of tuples, attributes, and domains in the delete operation? What is the role of general constraints and how are constraint violations handled? Can results of queries be used as parameters in delete operations? Give a small example.

3.3.3 Modify Facilities

Which of the database constituents can be modified? For each such constituent, describe the operation by its effect on the constituent being modified and on any other constituents.

Characterize the facility for the definition of modify operations. What is the perception of the user-supplied parameters in the modify operation (are they perceived as relations, as tuples, as input data used by a general facility for the redefinition of relations, etc.)? What is the role of tuples, attributes, and domains in the modify operations? What is the role of general constraints and how are constraint violations handled?

Give a small example.

3.3.4 Commit and Undo Facilities

Does the system provide facilities for making a sequence of tentative alterations which can, e.g., at the user's discretion, be committed (made permanent) or undone (called back to the state of the database before the alteration sequence).

3.3.5 Additional Alteration Facilities

Describe any facilities for altering database constituents other than by single insert, delete, and modify operations. Do not duplicate information in Section 3.4.

3.4 Additional Functional Capabilities

The following subsections describe features used to support the combined use of qualification, retrieval, and alteration.

3.4.1 Arithmetic and String Operations

What simple arithmetic expressions are supported? What substring and embedded string operations are supported? Do not repeat information in Section 2.

3.4.2 Sorting

Describe the facility for ordering the tuples in a relation; give the time period during which the ordering is supported.

3.4.3 Library Functions

Describe the library functions that are supported, e.g., aggregate functions such as MAY, MIN, SUM, COUNT, AVERAGE.

3.4.4 User Defined Functions

Describe the mechanisms that can be used to define functions over some database constituents. Can these functions be defined, added, deleted, and redefined through time?

3.4.5 Transactions

Does the system permit altering users to define "units of operations", i.e., transactions that perform meaningful database state transitions or state evaluations? How are these transactions defined? Is the user aware of concurrency of transactions?

3.4.6 Multi-tuple Alterations

Can more than one tuple of one relation be altered (i.e., inserted, modified, or deleted) using some tuples of another relation as arguments to the operation.

3.4.7 Grouping

Describe the facilities for grouping tuples (i.e., partitioning sets of tuples into distinct subrelations) for processing. What functions (library, user defined, sorting) can be applied to the resulting groups or partitions (average salary of employees grouped by department, count people grouped by age, etc.)?

3.4.8 Exception Handling Mechanism

Describe the mechanisms provided by the system for handling exceptional and error conditions. Can a user-specified sequence of operations be triggered automatically by some change in the database state or by the execution of some specified operations?

3.4.9 Additional Functional Capabilities

Describe any functional capabilities not described in subsections of 3.4.

4. Definition, Generation, and Administration Facilities

The development and maintenance of a database application involves at least the following four stages: database design, defining the database constituents to form a schema, generating an actual database by creating instances of the constituents (population is done by the facilities described in Section 3), and administering the maintenance and evolution of both logical and performance properties of the application. The facilities to support these states are described in the following subsections.

The description of these facilities should relate as closely as possible to the database constituents described in Section 2.0. However, the facilities may address different "levels" of the constituents, e.g., derived relations, base relations, domains, access paths, storage structures, etc. Difference in the levels of perception between Sections 2 and 4 should be distinguished. The "level" of each facility should be characterized. The various levels and their relationship should be characterized briefly here. The ANSI/SPARC architecture should be used _if_ it is appropriate.

Describe how the definition, generation, and administration facilities interact.

4.1 Definition Facilities

The following subsections deal with the definition of database constituents to form a database schema. Describe how the definition facilities interact (e.g., parts of one uniform language). Each subsection should describe definitional aspects only (e.g., notation, defining properties of constituents, naming limitations, expression of application rules) so as not to repeat information in Section 2. Give an example of a small database definition and refer to it in each of the following subsections. See comment j in RTG-80-90.

4.1.1 Constituents of a Database Definition

List the constituents of a database schema definition, e.g., the constituents described in Section 2 plus constraints, operations, and access paths. Place each constituent in a level given in Section 4.0 and characterize the relationships among constituents.

4.1.2 Database Definition

How are the properties of a database (2.2) defined? Are there limitations such as the number of constituents (e.g., relations)? Refer to the example.

4.1.3 Relation Definition

How are the properties of a relation (2.3) defined? Are there limitations such as the number of attributes, the order of definition, restrictions on defining keys? Are there extensions such as the ability to define foreign keys? Refer to the example.

4.1.4 View Definition

How are the properties of view (2.4) defined? Are there restrictions on defining these properties? If applicable, describe how dynamic and static derived relations (views) are defined. Describe how the view definition determines the operator set available for manipulating views.

Refer to the example.

4.1.5 Tuple Definition

How are the properties of tuples (2.5) defined (either explicitly or implicitly). Are there limitations on defining these properties?

Refer to the example.

4.1.6 Attribute Definition

How are the properties of attributes (2.6) defined (either explicitly or implicitly)? Are there restrictions on defining these properties, e.g., unique attribute name, aliases? What is the role of domains in the definition of attributes?

Refer to the example.

4.1.7 Domain Definition

How are the properties of domains (2.7) defined? List the built-in types on which domain definition is based. What are the restrictions on defining properties of domains? Can built-in data types be constrained to form new domains (restricted value set or operations)? Can a value set for a domain be defined by enumeration or other means? Can operations be defined over domains?

Refer to the example.

4.1.8 Definition of Additional Database Constituents

Describe the definition of any additional database constituents, e.g., snapshots, transaction, triggers, procedures. Database dictionary is to be described in subsection 4.5.

4.2 Generation Facilities

The generation of a database involved the processing of a database schema, the creation of (possibly empty) instances of database constituents, and possibly the population of the database. Some aspects of database generation are defined as part of the system generation while

others are defined as part of the application generation. This section describes the facilities for database generation.

Give a brief description of how a database is generated. Auxiliary mechanisms such as search aiding structures and details of how the database is generated need not be discussed.

Describe how these generation facilities relate to the other facilities of this section, i.e., 4.1, 4.3, 4.4, 4.5, as well as to the functional capabilities 3.0, if appropriate.

4.2.1 Constituents of a Database Generation

List the database constituents that are created during database application generation. Relate this list to Section 4.1.1. Only some of the constituents defined in 4.1, e.g., attributes, tuples, and relations, may be used to populate a database.

4.2.2 Generation of Database Constituents

Describe the facilities available for processing and populating database constituents. Briefly characterize any database load facilities and facilities for copying relations, particularly if they are relational in nature.

4.3 Database Redefinition

During the lifetime of the database it may become necessary to change the database definition. This may be as simple as renaming database constituents or it may require a redefinition of one or more database constituents.

4.3.1 Renaming Database Constituents

Describe the facilities for renaming each of the database constituents. Distinguish renaming from aliasing, which is the addition of synonyms to an existing name for a constituent. What are the restrictions on renaming? What is the effect on other database constituents that reference the constituent to be renamed? When does a schema change require changes to the database? To programs accessing the database?

4.3.2 Redefining Database Constituents

Describe the facilities for redefining database constituents. What changes to database constituents are permitted? What is the effect and required change to the schema and to the database? Can you redefine domains, attributes, tuples (by adding or deleting attributes), relations? Are there any restrictions on defining new views other than those given in 4.1.4? What is the effect on views based on relations that are redefined? Under what conditions can constraints be added to or deleted from the schema. What restrictions are there on redefinition?

4.4 Database Regeneration and Reorganization

During the lifetime of a database, logical changes to the application and the need to improve performance may require the database to be regenerated or reorganized. This section describes the facilities provided for these changes. Emphasize features that are relational in nature.

4.4.1 System-Controlled

Describe the changes to the database organization that are supported automatically by the system. Under what condition(s) does the system regenerate or reorganize the database? What is the extent of the changes that are system controlled (e.g., partial or full).

4.4.2 DBA-Controlled

Describe the facilities that the DBA can use to regenerate and reorganize the database. Under what conditions are such changes permitted, necessary, or desirable? Can a database be used to load a second database? What is the effect of each change?

4.5 Database Dictionary

Define the concept of database dictionary as supported by the system. What are its constituents? What information is stored in the data dictionary? What operations does it support (e.g., schema queries, system performance, data queries). How is authority granted to the facilities of the data dictionary? Does the data dictionary support database design, schema generation, etc.? Do the data dictionary languages differ from the database languages? Give a small example of their use.

5. Interfaces and DBMS Architecture

The purpose of this Section is to describe the various interfaces named in Section 1.6 and to describe their relationship within the DMBS architecture.

5.1 System Architecture

The various languages or interfaces of a DBMS are related in a DBMS architecture (e.g., the ANSI/X3/SPARC architecture). In this feature catalogue we are interested only in those interfaces or languages used by humans. We are not concerned with interfaces between system modules nor with any other implementation details. Describe the DBMS architecture as the relationship among the interfaces named in Section 1.6. Make this description as simple as possible by drawing a diagram of the architecture based on those used by C.J. Date in his book Introduction to Database Systems published by Addison-Wesley, second edition, 1976. Use two or three level schemas only if they are applicable.

5.2 Interface Descriptions

For each language named in Section 1.6, this Section should contain a subsection (e.g., 5.2.1, 5.2.2, etc.) which describes the language. The descriptions should be brief, not repeating information given elsewhere in the feature analysis. The following is an incomplete list of characteristics (and the subsection of the feature catalogue where they are described) to be considered in the description.

- name and purpose (1.6)

- problem class for which the language is intended (8.0)
- for what type of user is the language intended (ad hoc query, dba,...)?
- semantics: what database constituents (2) are accessible? what functional capabilities (3,4) are available?
- language form: linear (e.g., such as PL/1, PASCAL); graphic (e.g., tabular, menu); single or mixed (e.g., light pen and keyboard)
- language type: search/qualification complexity (3.1); relational algebra; relational calculus; block structured mapping; "natural" language.
- perception of relations (2.0): sets, tables, predicates, functions, etc.
- interactive features: are choices for responses fixed? is the dialogue user- or system-driven?
- self-contained features: Can parts of the language be used on a stand-alone basis? What is the computational power of the self-contained portion of the language (e.g., relational algebra, relational calculus, see Sections 3 and 4)?
- host language features: is access to a relational database provided by features that are extensions to (e.g., procedure calls that put results into workspaces) or embedded in the related database management system (e.g., relation-like structures built into the language)? Describe the interface between the host language and the relational database facilities. How is database status information passed to the host language? How is data from the database passed to the host language? Does the user access the database through procedure calls or directly through the data structures and operations in the language? Characterize the level of procedurality (e.g., record or set oriented, power of qualification).
- What the the security features provided by the language? (6.1)
- Describe the recovery features of the language. (6.2)
- Describe any special features of the language.
- Give a brief example to illustrate the use of each main feature of the language. Refer to examples given in Sections 3 and 4 for features already illustrated.

6. Operational Aspects

6.1 Security

This section discusses the security features provided by the system.

6.1.1 Access Control

Describe the facilities provided by the system to protect against unauthorized access. Describe the logging and audit trail facilities. How are users identified or authorized in access control based on operations, access paths, data values, etc.? How are security violations handled? Does the system support the definition and maintenance of private relations?

6.1.2 Capability

Describe the possible security domains and their potential capabilities. How are these domains and capabilities defined?

6.2 Physical Integrity

This section describes the mechanisms for ensuring integrity of the database under sequential and concurrent access.

6.2.1 Concurrency Control

Discuss how the system handles the concurrent alteration problem. Are these aspects transparent to altering users or can they control the level and effects of concurrency. How are concurrency related problems (lost updates, phantoms, deadlock) resolved? Can database queries be executed concurrently?

6.2.2 Crash Recovery

Describe the capabilities provided to ensure against failure, e.g., backup, restart, checkpoint, logging, restore, undo.

6.3 Operating Environment

This section discusses the hardware and software environment of the DBMS.

6.3.1 Software Environment (Operating System)

The reliance of data management systems on executive, control, or operating systems varies widely. Some rely heavily on manufacturer's supplied operating systems, others rely only on programming language compilers, while some include, within the data management system, those functions normally performed by the operating system. This section attempts to characterize the system being discussed according to the above spectrum.

6.3.2 Hardware Environment (CPU, Memory, Peripherals)

All systems are implemented or are being implemented on at least one hardware configuration and may be implemented on many. The description of the hardware environment covers the CPU, memory, and peripherals that are

minimum, and which is recommended.

What is the size in bytes of the relational database system? Differentiate, if possible, by giving the size of the major components.

7. Essentially Relational Solutions for Generalized DBMS Problems

Research and development based on the relational approach to databases has provided solutions applicable to generalized DBMS problems, i.e., applicable to more than just the relational approach. This Section describes these solutions and other advantages of the relational approach to databases.

Consider each of the following claimed advantages of the relational approach and, where applicable, describe briefly how the advantages are realized in the system or language under consideration. (Feel free to add to the list of claimed advantages.)

- Simplicity. Based on the simple and well understood nature of set-theory and predicate calculus there is an economy of concepts. There is one major data structure, the relation, and a small set of operations forming the relational algebra.
- Uniformity. Relational algebra and relational calculus exhibit closure and can be used as a basis for all forms of interaction with the database.
- Data Independence. Relational schemes and languages are free of many representational details such as access paths, ordering, and indexes. The relational algebra and calculus are high-level (non-procedural) and set-oriented.
- Permits optimization. The lack of representational detail in relational languages allows for the possibly automatic optimization of database interactions. (You may wish to describe any optimization the system does for interactions.)
- Basis for high level interfaces. Non-procedural, set-oriented relational languages permit the user to deal with the information in an application-oriented manner by being able to ignore many representational details. Relational languages can be extended easily to other high level interfaces. Considerable research on query languages is based on the relational approach.
- Natural. The set, table-like or predicate perceptions of data may be particularly appropriate for certain classes of applications.
- Efficient storage and retrieval potential. The high level, set-oriented nature of the relational model can be used to take advantage of database machines.

- Multiple views of data. The relational algebra permits dynamic definition of new user views which can be derived from existing relations.
- Advantages for distributed databases? Relational languages are independent of access paths and location of the data. This may provide benefits for distributed databases where distribution is intended to be transparent to the user.
- Security? Access paths are defined by the use of the relational algebra or calculus rather than being explicit.
- Basis for database semantics. The relational approach permits a distinction between data structure and data semantics. Data structure concerns relations, the representational tools. Relations are simple and "uninterpreted". Data semantics concerns the properties of the database application that are to be represented using relations plus additional constraint mechanisms. In this approach the relational database model is a basis for database design and semantic database models, e.g., constraints can be expressed using first order predicate calculus.

  Some other advantages for database semantics are:
  - Relationships are explicit in relations. Relationships exist either in relations or can be derived dynamically from existing relations using the relational algebra.
  - Relativism. A relation can be viewed as representing an entity or an n-ary relationship.
  - Symmetry. A relationship A 0 B can be accessed and expressed with equal facility in both orders A to B and B to A.

- Strong theoretical foundation based on the mathematical concept of relation, on set theory, and on first-order predicate calculus. This theory has provided a basis for the study of the following aspects of databases:

  - normalization theory
  - consistency
  - redundancy
  - derivability
  - analysis of relational schemes, altering operations and queries
  - schema mappings
  - completeness of database languages with respect to relational calculus (or DSL ALPHA) as a means for evaluating database languages
  - query processing, i.e., logical deduction, optimization of query evaluation

- database design

8. Database Applications Using the System

This Section is intended to characterize the practical uses of the system: How widely used is the system (number of running applications)? What is the nature of the class of actual uses of the system? Give statistics concerning known applications, i.e., numbers and sizes of database constituents. Give the actual use of functional capabilities, transaction types (e.g., insert, update, delete) and loads, query activity, types of interfaces and their actual usage. How often has the schema been altered since the database was first loaded? What types of views (e.g., dynamic, static, snapshot) are used? How important is security? How complex is semantic integrity? What is the size of the schema and its associated procedure library (i.e., number of schema constituents and number of procedures)? How long have these applications been in existence? Describe unique or novel features common to applications using the system. What characteristic of these EBMSs is unique to the relational approach? What type of system (if any) was it running on in the past?

4. Using the Feature Catalogue

4.1 How the Analyses Were Performed

The feature analyses were performed for selected DBMSs that were claimed to support significant aspects of the relational data model. By means of letters, telephone calls, press releases, and announcements at database conferences, the RTG requested assistance from developers of these systems in completing the feature analyses. Responses were received from twenty-two developers. To avoid possible bias in analyzing the systems, RTG members completed the analyses themselves. The following criteria were used in selecting systems for analysis:

1. Availability of documentation on the system.

2. Stấtus. Systems that have been released to users other than the development staff (and that support some applications) are preferred to purely research vehicles.

3. Significance. Systems that have been used as models, like SEQUEL/SYSTEM R, are preferred to relatively unknown systems like ASTRAL.

4. Significance within the sample. An effort was made to include systems that illustrate a variety of approaches to RDBMSs and to interfaces.

5. Existence of a volunteer to perform the analysis.

The following systems were analyzed in the terms of the final feature catalogue:
IDM (Britton-Lee)
INGRES (University of California, Berkeley)
IPIP (Boeing Computer Services) -- incomplete feature analysis)
MRDS (Honeywell)
MRS (University of Toronto)

NOMAD (National CSS, Inc.)
ORACLE (Relational Software Incorporated)
PASCAL-R (Hamburg University)
PRTV (IBM, United Kingdom)
QBE (IMB, Thomas J. Waston)
RAPID (Statistics Canada)
RAPPORT (LOGICA, United Kingdom)
SYSTEM R (IBM San Jose)

The completed feature analyses are included in Section 6 of this report.

The analyses were performed by members of the RTG and were reviewed by at least one other member. Whenever possible, analyses were sent to the manufacturers, designers, or vendors of the systems for comment. A number of analyses were performed by people working for the company or university where the system originated.

Once completed, the individual feature analyses were compared in order to determine the state-of-the-art and to categorize the features according to the taxonomy given in the next Section 4.2. The result of this comparison is given in "The Final Report of the ANSI/X3/SPARC DBS-SG Relational Database Task Group".

4.2 Notes on Completing a Feature Analysis

These notes were given as a guideline to completing a Feature Analysis.

4.2.1 Purpose and Benefits of a Feature Catalogue

The purpose of the feature catalogue is to organize the RTG's investigation of the relational database model and of the features of systems supporting aspects of the RDM. The objective of the analysis is to get insight into:

1. the relational database model
   a. essential or kernel concepts, and secondly
   b. additional concepts or extensions.

2. system issues concerning the support and use of the RDM.
   a. kernel aspects, such as those concerning interfaces
   b. adjuncts or nonrelational concepts, e.g., locking, concurrency, security, access control.

When including a concept in the feature catalogue for the analysis we must ask:

- is it inherently part of the relational approach?

- is it necessary to support relational concepts?

- is it distinct from nonrelational models and systems?

The objective of the feature analysis is to produce:

- a final RDM definition based also on the results of other subtasks;

- a catalogue of features of systems supporting relational concepts; and

- a feature analysis of several such systems.

The resulting definitions, terms and feature catalogue will be used to write and support all sections of the SD3 especially scope and program of work, benefits and feasibility.

The specific information gathered will permit us to categorize the features according to Arthur's taxonomy (RTG-80-72):

1. Features that appear in every system which is claimed to be relational.

2. Features that do not appear in every system but are rapidly being added to many systems.

3. Features that are felt to be important but do not yet appear other than in the literature or in research systems.

4. Features that have been in some systems for some time but do not appear to be spreading to other systems, e.g., due to performance problems.

5. Features that distinguish the relational approach from all other approaches, i.e., features which must not be present (explicit pointers visible at the user interface).

Clearly, features in categories 1 and 2 would form the basis of a standard, while features from categories 3 and 4 could be used as a basis for future developments. Features in Section 5 would be used to exclude nonrelational systems.

A feature catalogue would have additional benefits:

- supply educational aid
- develop a specific knowledge of the state of the art and be able to relate it to research and development results
- provide specific details to support the SD3
- demonstrate the amount and nature of work in implementations, applications, and literature
- determine to what extent RDM concepts are constrained when implemented

In order to achieve its objectives for the feature analysis, the RTG will concentrate on certain RDBMSs or families of RDBMSs. The total number will be related to the number of RTG members since to be objective, the RTG will control the writing of the feature analyses and correlate the results.

A feature analysis should be completed for a system if:

- it clearly contributes to the objectives;
- it is on an existing system, otherwise a strong argument must be made with respect to (i) for systems in development or design;
- it is widely known and used;
- the RTG has the resources to do the work.

If two or more systems are very similar, e.g., based on SQL, then they will be treated together with an indication of unique contributions of individual systems.

With the above issues in mind the RTG wil support two activities: conduct feature analyses of selected systems (see RTG-80-81) and create a roster of DBMSs claiming to support relational concepts.

Whether candidates for the feature analysis end up in the final report depends on whether the analysis is completed and whether the system makes a unique contribution.

A possible table of contents for the final feature analysis report:

1. Feature analysis introduction

2. RDM Concepts and terms
   a) Introduction (informal definition)
   b) Definition (more formal definition)

3. Feature catalogue (revised as a result of the FAs)

4. Feature analysis of selected systems

5. Discussion of relational systems

6. Discussion of terminology

7. Discussion of RDM definition

8. Roster of systems supporting relational concepts

4.2.2 Development Status

The development plan for the feature catalogue is as follows:

i) Develop an understanding of the issues by applying a modified version of the 1969 GDBMS feature catalogue to some existing relational and nonrelational systems.

ii) Using the knowledge and experience from the first phase, develop a feature catalogue appropriate to RTG objectives. RTG members were asked to criticize the modified 1969 catalogue or to propose a new feature catalogue.

iii) Apply the feature catalogue resulting from (ii) to selected systems in order to get feature analyses.

iv) Revise the feature catalogue based on the resulting feature analyses in order to indicate what features are common to many, few, one or no systems.

What has happened so far is that:

i) The modified 1969 catalogue was prepared and more than ten feature analyses were attempted.

ii) A feature catalogue was developed by Schmidt, et al., with comments from a number of other people, including several RTG members.

iii) Schmidt's proposed feature catalogue was substantially reorganized, extended, and revised, resulting in the current feature catalogue.

iv) The feature catalogue has been distributed in order to direct feature analyses of selected systems (see RTG-80-81).

4.2.3 Development Plan

The following is the schedule for developing the feature catalogue:

ACTIVITY		DUE DATE
Distribute feature catalogue to RTG members		June 20
RTG member responsible for a Feature Analysis:		
(i)	prepare by contacting	
	RTG reviewer responsible organization system user	June 20
	and by ensuring you have the appropriate documents	
(ii)	complete the first draft of the Feature Analysis	July 20
(iii)	receive revisions to draft from RTG reviewer	August 1
(iv)	receive revisions to draft from organization	September 10
(v)	receive revisions to draft from user group	September 10
(vi)	complete revision of draft	September 20
revise Feature Catalogue to reflect facts gained during feature analysis		September mtg.

4.2.4 Comments on Completing a Feature Analysis

a. Terminology

Use the terminology of the system being described but provide (for readability) a terminology translation table at the front of the feature analysis and explicitly indicate equivalence by "system-term (=feature catalogue term)" wherever possible.

b. Example Feature Catalogue

Please consult Schm's feature analysis of Pascal/R (RTG-80-70) for examples of what to say. Note that he used the old catalogue which has since been reorganized.

c. WHAT not HOW

The emphasis for the feature catalogue is WHAT the features are and WHAT they mean, not how they are implemented. Lower level details (e.g., 1.3, 3.2.3, 4.2.8, 6.0, etc.) and features that are not essentially relational in nature (e.g., 3.2.2, 3.2.4, 3.3.5, 3.4, 6.0) should receive less emphasis than logical, purely relational features (e.g., sections 2, 3 and 4). Emphasize the meaning (semantics) of features rather than their syntactic aspects.

d. Repetition

Try not to repeat any information. If the same information is applicable to more than one subsection, describe it in the most appropriate place and use references to that place for each of the other subsections.

e. "Additional" Subsections

If the feature catalogue does not provide for the explicit description of some feature that you feel is important, describe it on the appropriate subsection entitled "additional...".

f. Completeness

The feature catalogue may ask for descriptions of features not present in the system being described (e.g., tuples and attributes may not be supported explicitly). Attempt to see if the feature is supported implicitly. If it is not supported at all, write "Not Supported" in the appropriate subsection.

g. Essentially Relational Features

Please propose candidate features for inclusion in subsection 1.5 and 7. This is of prime importance to the work of the RTG.

h. Final Product

After the analyses are completed, we will have to review and compare all of them. Please complete your feature analysis with this in mind, i.e., use the feature catalogue outline wherever possible, be careful with terminology, etc.

i. Alternative Feature Description

Sections 2 and 4 attempt to distinguish different constituents; however, in some systems this may not be easy (natural), e.g., attributes and tuples may be described only in the context of relations. Please follow the current feature catalogue as far as possible. If you feel strongly that Schmidt's earlier catalogue is more appropriate (i.e., treat all constituents as relations and their constituents, then domains) please fill out that part of that catalogue also. We will resolve this issue during the final edit of the feature analyses. (If you do not have Schmidt's Catalogue please contact Michael Brodie.)

j. A Toy Database Example

Throughout the feature catalogue, you are asked to show an example of the use of particular features. Specifically, you are asked to give examples in:

- all subsections of 3.1, 3.2, 3.3, 3.4
- all subsections of 4.1, 4.2, 4.3, 4.4, 4.5
- each subsection of 5.2

Additionally, examples may be useful in Sections 6.1 and 6.2.

The examples will be used to illustrate particular features of the language or system under consideration. However, for the objectives of RTG the features of all systems must be compared. The comparison will be exceedingly difficult if each feature catalogue uses a different example. Everyone is being asked to use the same example. The most readily available example is the example used throughout Date, C.J., An Introduction to Database Systems, 2nd ed., Addison-Wesley, 1976 (i.e., relations S, P, SP (page 52); also, if needed, S, P, J, SPJ on page 52). Please use this example for the sections listed above. If Date's example does not contain a feature you wish to illustrate, extend the example rather than introduce a new example.

k. Liaison with the System's Organization

If you have not contacted the system's organization you should do so as soon as possible. Things that you might find helpful are:

- a person to contact for any questions you may have

- a bibliography of documents or literature on the system

- actual documents needed. You will need them for yourself, for your reviewer, and for the RTG repository

- a contact person in a group that uses the system.

Finally, you should set up a schedule with the organization for completing their review of your feature analysis. You might send them a copy of the feature catalogue to help them prepare.

4.3 Problems with the Feature Catalogue

When the completed feature analyses were reviewed, a number of problems were found with the wording and organization of the feature catalogue. If we were to do another iteration of the feature catalogue, it would be revised to reflect our new understanding of RDBMSs and of how people answered the questions. For the purposes of this report, we have not modified the catalogue on which analyses were based. Problems encountered in using the feature catalogue and the resulting analyses are listed below by sections of the feature catalogue. They should be considered as footnotes to the feature catalogue, and they may help to explain ambiguous or contradictory responses in the analyses.

<u>Section 1.5</u>

The characterization by Codd of a "fully relational system" [CODD80] was partially quoted in Section 1.5 of the feature catalogue. The term is referenced by a number of system analyses, but there appears to be at least two misunderstandings.

First, Codd's characterization requires that a language "at least as powerful as the relational algebra" be available. The absence of an explicit mention of a relational calculus caused authors of some system analyses to feel uncomfortable about systems with calculus based languages, although both kinds of languages are completely equivalent.

Second, several "insert-update-delete" rules introduced by Codd are specific to the version of the relational model presented in that paper. The inclusion of all such rules was not intended. This led to misunderstandings in a number of system analyses. No system supports all of the rules defined in [CODD80].

Section 1.6

The intent of Section 1.6 was not to ask whether thirteen separate interfaces existed, but to list groups of capabilities which might reasonably be expected to be supported in some interface. This intent was not made explicitly. Information which would answer 1.6 is found scattered through the analyses.

The question of report generation (1.6-7) is an exception to the above statement. There is some interest in whether report generation is supported by a special-purpose interface; this is not a relational issue but an architectural question. This should have been treated differently than the other items in 1.6 so as to make it clear what information was wanted.

Section 2

Much of the material in Section 2 should be in Section 4. The catalogue might be improved by deleting the sections in Section 2 relating to operations and constraints.

In 2.2.2, it was not clear to respondents what was meant by "database operations." Some reviewers indicated that commands such as BACKUP, DISPLAY, RESTORE, and PROTECT were database operations. Others listed CREATE, DROP and EXTEND (relation) as database operations, since they changed the database schema.

Responses were varied with regard to the constraints on each database constituent. Three types of constraints were noted:

1. system limitations -- for example, all relations must have primary keys;

2. semantic constraints -- for example, user-defined constraints upon the content of constituents;

3. operational constraints.

Constraints listed in 2.5.1 and 2.5.3 really apply to relations, not to tuples, and should have been put in Section 2.3.

If functions are supported, they should be described in Section 2.7 (domains) rather than in 2.6 (attributes).

The notion of "domain" in 2.7 should be more than a simple data type. This may not have been clear. What was intended was the notion of a user-defined domain; for example, the ability of the user to define a domain COLOR consisting of the set of values "red", "white", and "blue".

In almost all cases, the constituents entered under the subsection "Additional Properties" were found later in another section. Responses to this section were not uniform, indicating that the respondents were not clear about what was expected.

Section 3

We found that the feature catalogue had little relation to the features explicitly described in analyses. Answering any question in the feature catalogue required looking through all of Section 3. Were we to revise the catalogue, this section would be totally restructured.

The questions about nesting and closure (3.1.5) were poorly understood and we have little confidence in the results. An explanatory paragraph would have been helpful.

In Section 3.2.1, "Database queries", we hoped for explicit information about specific capabilities, but we did not list the capabilities we were interested in obtaining. In effect we asked respondents to analyze the functionality of the interface for us. Many of them, instead, wrote down an example of query syntax.

The section on report generation (3.2.4) did not ask questions at a level of detail appropriate for systems that had powerful generators.

No respondent understood what was meant in Section 3.4.5, "Transactions". It is not clear that the task group has reached any consensus on the meaning of this section.

Section 4

Practically all of Section 4 is covered elsewhere, either in 2 or in 1.6. Many of the respondents referred the reader to Section 2, indicating that it had already been covered in that section.

The term "view" was interpreted differently by different respondents. Is a view a relation of a subschema? If a view is a relation, is it a static or a dynamically derived relation? Some of the respondents went into great detail regarding views. They discussed such things as operations on views, views defined from other views, and handling keys with regard to views. Other respondents did not mention these aspects.

Section 6

The intent of Section 6, "Operational Aspects", was to support the statement that there are existing, practical database management systems supporting the relational model. The section may have been more successful if the features on which information was desired had been described in more detail, and if the purpose of the section had been made explicit.

5. References

The following documents were used in the preparation of the feature analyses.

[ALDR76]
Aldred, B. and B. Smedley. "An Urban Management System -- A General Overview". Research Report UKSC 81, 1976.

[ALDR77]
Aldred, B., S. Huyshe and A. Storey. "Information Systems for Agricultural Crop Research". Research Report UKSC 103, IBM UK Scientific Centre, Peterlee, England.

[ADIBA76]
Adiba, M. and B.G. Lindsey. "Database Snapshots". Research Report RJ, IBM Research Laboratory, San Jose, California.

[ALDR74]
Aldred, B. and B. Smedley. "UMS Technical Overview". Research Report UKSC 50, 1974.

[ARTH80]
Arthur, A. "Committee Correspondence on the Feature Catalog". Working Paper RTG-80-72, April 25, 1980.

[ASTR80a]
Astrahan, M.M., W. Kim, and M. Schkolnick. "Evaluation of System R Access Path Selection Mechanism". Research Report RJ2797, IBM Research Laboratory, San Jose, California, April 1980.

[ASTR80b]
Astrahan, M.M. et al. "A History and Evaluation of System R". Research Report RJ2843, June 12, 1980.

[ASTR76]
Astrahan, M.M. et al. "System R: Relational Approach to Database Management". ACM TODS, Vol. 1, No. 20, June 1976.

[BERT76]
Bertrand, O. "NLS, A Generator and Interpreter of User Languages". Proc. of IBM Int'l. Conf. on Relational Database, Bari, 1976.

[BLAS79]
Blasgen M.W. et al. "System R: An Architectural Update". Research Report RJ2581, July 1979.

[BOYC73]
Boyce, R.F., and D.D. Chamberlin. "Using a Structured English Query Language as a Data Definition Facility". Research Report RJ1318, December 1973.

[BRLE80]
Britton-Lee Incorporated. IDM Software Reference Manual Version 1. 1980.

[CHAM76b]
Chamberlin, D.D., et al. "SEQUEL 2: A Unified Approach to Data Definition, Manipulation and Control". IBM Jour. of Research and Development, November 1976, pp. 560-575.

[CHAM77]
Chamberlin, D.D., et al.
"Database System Authorization". Research Report RJ2041, July 1977.

[CHAM79]
Chamberlin, D.D., et al. "Support for Repetitive Transactions and Ad-Hoc Query in System R". Research Report RJ2551, May 1979.

[DITT79]
Dittli, A.L. Introduction to FRAMIS -- A Tutorial. Lawrence Livermore Laboratory, March 1979.

[DOTZ80]
Dotzek, W.H., M. Mall and J.W. Schmidt. "Feature Catalogue for Relational Concepts, Languages and Systems (3rd Version)" PASCAL/ R MEMO 21-80, Fachbereich Informatik, University of Hamburg, Hamburg, West Germany, February 1980.

[DUBE80]
Dube, R.P. et al. "An Approach for Management of Geometry Data". IPAD National Symposium, Denver, Colorado, September 17-19, 1980.

[EPST77]
Epstein, R. "Creating and Maintaining a Data Base Using INGRES". ERL Technical Memorandum M77/72, University of California, 1977.

[EPST80b]
Epstein, R. and P. Hawthorn. "Design Decisions for the Intelligent Database Machine". Proc. of the 1980 NCC.

[HAWT79]
Hawthorn, P. and M. Stonebraker. "The Use of Technological Advances to Enhance Data Management System Performance". ERL Technical Memorandum M79/3, University of California, 1979.

[HELD75]
Held, C.D., M. Stonebraker and E. Wong. "INGRES: A Relational Database System". Proc. ACM Pacific 75 Regional Conf., pp. 409-416.

[HITC76]
Hitchcock, P. "User Extensions to the Peterlee Test Vehicle". Systems for Large Data Bases. Amsterdam, Holland, 1976., pp. 169-180.

[HONE78a]
Honeywell. Multics Linus Reference Manual. Preliminary Edition. March 1978.

[HONE78b]
Honeywell. Multics Relational Data Store (MRDS) Reference Manual. March 1978.

[HUDY79]
Hudyma, R., I. Ladd and J. Kornatowski. "Implementing a Microcomputer Database Management System". Computer Systems Research Group, University of Toronto, 1979.

[HUDY78]
Hudyma, R. "Architecture of Microcomputer Distributed Database Systems". MSc Thesis, University of Toronto, 1978.

[IBM79]
IBM Scientific Centre, Peterlee, England. PRTV User Manual. Technical Note 34.

[IBM78]
IBM Corporation. Query-by-Example Terminal User's Guide. IBM Manual SH20-2078.

[IBM77]
IBM Corporation. Query-by-Example Program Description/Operations Manual. IBM Manual SH20-2077.

[JOHN80a]
Johnson, H.R. "Relational Feature Analysis of IPIP, the IPAD Database Management System". RTG Working Document, September 1980.

[JOHN80b]
Johnson, H.R., D.L. Comfort and D.D. Shull. "An Engineering Data Management System for IPAD". IPAD National Symposium, Denver, Colorado, September 17-19, 1980.

[JONES79c]
Jones, S.E., D.R. Ries, L. Lyles and A.L. Dittli. Framis Reference Manual. September 1979.

[KIM79]
Kim, W. "Relational Database Systems". ACM Computing Surveys, Vol. 11, No. 3, September 1979.

[KINS80]
Kinsley, K. "A Bibliography on the Relational Approach to Databases". RTG Working Document, May 1980.

[KORN79]
Kornatowski, J.Z. MRS Users Manual. Computer Systems Research Group, University of Toronto, July 1979.

[LADD79]
Ladd, I. "A Distributed Database Management System Based on Microcomputers". MSc Thesis, University of Toronto, July 1979.

[LOGI80a]
Logica Limited. RAPPORT User Manual. February 1980.

[LOGI80b]
Logica Limited. Rapport Interactive Query Language User Manual. February 1980.

[LOGI79a]
Logica Limited. Introduction to RAPPORT. December 1979.

[LOGI79b]
Logica Limited. Designing and Using a Database. December 1979.

[MAND73]
Mandil, S. "The MP/3 Macroprocessor". Research Report UKSC 44, 1973.

[McCR79]
McCracken, D.D. "Examples of NOMAD as a Relational Database System". April 1979.

[NATI80]
National CSS, Incorporated. NOMAD2 Features and Capabilities. Form 1004Y. May 1980.

[NATI79]
National CSS, Incorporated. NOMAD Reference Manual. Form 1004-2, November 1979.

[NOTL72a]
Notley, M.G. "A Model of Extensible Language Systems". UKSC 22, March 1972.

[NOTL72b]
Notley, M.G. "The Peterlee IS/1 System". Research Report UKSC 18, March 1972.

[NOTL71]
Notley, M.G. "Extensibility in Information Systems". Symposium on Extensible Languages, Grenoble, September 1971.

[PODE72]
Podehl, W.M. "STATPAK - General Concepts and Features". Statistics Canada, Ottawa, Canada, 1972.

[SCHM77]
Schmidt, J.W. "Some High Level Language Constructs for Data of Type Relation". ACM TODS, Vol. 2, No. 3, September 1977.

[SCHM80a]
Schmidt, J.W. and M. Mall. "PASCAL/R Report". Bericht Nr. 66, University of Hamburg, Federal Republic of Germany, January 1980.

[SCHM80b]
Schmidt, J.W., M.L. Brodie, M. Mall, and W.H. Dotzek. "Feature Catalogue of Relational Concepts, Languages and Systems". Working Paper RTG-80-81, April 1980.

[SELI79]
Selinger, P.G., et al. "Access Path Selection in a Relational Database System". Research Report RJ2429, January 1979.

[SEPB72]
Swedish Environment Protection Board and IBM Sweden. "An Experiment Using Database Techniques in Environment Research". IBM Sweden, November 1972.

[STAM78]
Stamper, R.N. "The LEGOL Project, A Survey". Research Report UKSC 81, June 1978.

[STCA79a]
Statistics Canada. Database Performance. Ottawa, Canada, March 1979.

[STCA79b]
Statistics Canada. Rapid Language Reference. Ottawa, Canada, December 1979.

[STCA79c]
Statistics Canada. Rapid Programmers Guide. Ottawa, Canada, December 1979.

[STCA79d]
Statistics Canada. Rapid Utilities. Ottawa, Canada, March 1979

[STCA78a]
Statistics Canada. Rapid Meta-Data Memory. Ottawa, Canada, June 1978.

[STCA78a]
Statistics Canada. ADABAS/RAPID Demonstration Database. Ottawa, Canada, June 1978.

[STCA78b]
Statistics Canada. Rapid Retrieval. Ottawa, Canada, June 1978.

[STCA78b]
Statistics Canada. Rapid Database Creation. Ottawa, Canada, June 1978.

[STCA78c]
Statistics Canada. Rapid DBMS. Ottawa, Canada, June 1978.

[STCA76]
Statistics Canada Rapid File Design. Ottawa, Canada, June 1976.

[STON78]
Stonebraker, M. "Concurrency Control and Consistency of Multiple Copies of Data in Distributed INGRES". ERL Technical Memorandum Reprint 1702, University of California, August 1978.

[STON76]
Stonebraker, M. et al. "The Design and Implementation of INGRES". ERL Technical Memorandum Reprint 1468, University of California, September 1976.

[STON75]
Stonebraker, M. "Implementation of Integrity Constraints and Views by Query Modification". Proc. Int'l. Conf. on Management of Data, 1975, pp. 65-78.

[STOR79a]
Storey, R.A. "World Health Organisation/IBM UK Scientific Centre Joint Study on the Design of Information Systems". Research Report UKSC 105, January 1979.

[STOR79b]
Storey, R.A. "An Evaluation of the Peterlee Relational Test Vehicle". Research Report UKSC 106, August 1979.

[STOR79c]
Storey, R.A., M. Bunzel and N. Ourusoff. "Report of the World Health Organisation Information Systems Programme and IBM UK Scientific Centre Study on the Design of Information Systems". Research Report UKSC 105, January 1979.

[TANN80]
Tanner, J.G., D.M. Kirkwood and F.M. Ives. "Executive and Communications Services to Support the IPAD Environment". IPAD National Symposium, Denver, Colorado, September 17-19, 1980.

[TODD76]
Todd, S.P.J. "The Peterlee Relational Test Vehicle - A System Overview". IBM Systems Jour., No. 4, 1976.

[TURN79]
Turner, M.J., R. Hammond and P. Cotton. "A DBMS for Large Statistical Databases". Systems Development Division, Statistics Canada, Ottawa, Canada,

September 1979.

[TURN75a]
Turner, M.J. "Data Management at Statistics Canada". Systems Development Division, Statistics Canada, Ottawa, Canada, March 1975.

[TURN75b]
Turner, M.J. and M. Podehl. "GSS Plans for a Generalized Database Management System". Systems Development Division, Statistics Canada, Ottawa, Canada, October 1975.

[TURN74]
Turner, M.J. "The Impact of Data Bases on Statistical Agencies". System Development Division, Statistics Canada, Ottawa, Canada, January 1974.

[TURN72]
Turner, M.J. "A New File-Type for TOTAL or How and Why Statistics Canada Has Widened the Scope of the TOTAL DBMS". Systems Development Division, Statistics Canada, Ottawa, Canada, December 1972.

[WEEL79]
Weeldreyer, J.A. and O.D. Friesen. Multics Relational Data Store: An Implementation of a Relational Data Base Manager. Multics Software Development Unit, Honeywell Information Systems, Inc., Phoenix, Arizona.

[WOOD79]
Woodfill, J. et al. INGRES Version 2 Reference Manual, ERL Technical Memorandum M79/43, University of California, 1979.

[ZLOOF78a]
Zloof, M.M. "Query-By-Example: Operations on the Transitive Closure". IBM Research Report RC5526, IBM Thomas J. Watson Research Center, Yorktown Heights, New York, February 7, 1978.

[ZLOOF78b]
Zloof, M.M. "Security and Integrity Within the Query-By-Example Data Base Management Language". IBM Research Report RC6982, February 7, 1978.

[ZLOOF77]
Zloof, M.M. "Query-By-Example: A Data Base Language". IBM Systems Jour., No. 4, 1977.

[ZLOOF76]
Zloof, M.M. "Query-By-Example: Operation on Hierarchical Data Bases". AFIPS Conf. Proc., NCC 45, 1976, pp. 845-853.

[ZLOOF75a]
Zloof, M.M. "Query-By-Example". AFIPS Conf. Proc., Vol. 44, AFIPS Press, Montvale, N.J., 1975.

[ZLOOF75b]
Zloof, M.M. "Query-By-Example: The Invocation and Definition of Tables and Forms". Proc. of the Int'l. Conf. on Very Large Data Bases. Boston, Massachusetts, September 22-24, 1975, pp. 1-24.

6. Feature Analyses

This section consists of individual feature analyses for thirteen (13) systems. Each feature analysis was prepared using the "Feature Catalogue of Relational Concepts, Languages and Systems" given in entirety in Section 3 of this report.

All feature analyses, except that of IDAM, were prepared in conjunction with the RTG and were considered in the comparison of systems reported in the Final Report of the Relational Database Task Group. The IDAMS feature analysis was submitted too late to be included in the comparison.

Feature Analysis of Relational Concepts, Languages, and Systems for IDM*

by
Daniel R. Ries

Computer Corporation of America
575 Technology Square
Cambridge, Massachusetts 02139

October 1980

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*Prepared while the author was at Lawrence Livermore Laboratory.

IDM 0

Feature Analysis of Relational Concepts, Languages and Systems for IDM[TM]

Prepared by:

Daniel R. Ries
October, 1980

FORWARD

This report was prepared for inclusion in a Feature Catalogue of Relational Concepts, Languages and Systems being prepared by the Relational Database Task Group of ANSI/X3/SPARC - Database Systems Study Group. The format and content of the report are based on the Working Paper RTG-80-81 of the relational database task group. This report compared IDM to the terms and definitions of that paper and not to other commercial products.

[TM] Intelligent Database Machine (IDM), Intelligent Database Language and IDL are (applied for) trademarks of Britton-Lee, Inc.

1 INTRODUCTION

1.1 Identification

Intelligent Database Machine (IDM) 500

Developed by: Britton-Lee, Inc.
Albright Way
Los Gatos, California

1.2 Status

1.2.1 System

The IDM will be released in the 4th quarter, 1980.

1.2.2 Applications

The IDM is designed for use by OEM companies who will provide the direct support and/or applications for the end users.

1.3 System Background

The IDM system is a database machine and as such is not part of any particular family of systems. The reference manual uses the Intelligent Data Language (IDL) to describe the functionality of the IDM and IDL very strongly resembles the Quel language of INGRES. However, other relational languages could also be interfaced to the IDM.

1.4 Overall Philosophy

The IDM is a self-contained system that serves as a dedicated peripheral providing a relational database management system. The IDM provides a high level 'host independent' interface to OEM supplied programs running on the host. The OEM supplied interface can support an interactive set oriented language based on the relational calculus (or algebra) and/or a tuple at a time interface.

1.5 Essentially Relational Characteristics

The system is fully relational. It provides all of the power of the join operation including cycles, self-joining relations, multiple joins, and independent existence of relations.

It has the advantages of a relational system including no access path dependencies, no order dependencies, no index dependencies, no altering dependencies, high-level interface, and dynamic views. It does not specifically support semantic integrity constraints except through the use of stored user commands. It does allow protection constraints to be dynamically added and deleted.

1.6 Interfaces

(1) Database Schema Definition

(2) Query Language

(3) Database Altering

(4) Constraint Definition

(5) Database Generation and Regeneration

(6) Database Schema Redefinition and Renaming

(9) Security Definition, Monitoring and Control

(10) Database Control Utilities

(11) Definition of Storage Structure, Indexes and Access Paths

(12) Database Dictionary

The language for all of these interfaces is basically a set of <token, values> that result from the OEM supplied parser or program interface.

IDM provides guidelines and a suggested End User Language (IDL) for implementing: a full purpose query language, a specific subroutine call interface and an imbedded programming language.

Regardless of the interface the OEM provides, it must be translated into the 'correct' sequence of tokens and values. That sequence is described as a post-order traversal of the IDL parse tree.

Results, both status and data, are returned to the host using the same <token, values> protocol.

1.7 Documentation

IDM Software Reference Manual Version 1.0 Copyright 1980.

"Aid in the '80s" by Robert Epstein, Paula Hawthorn in DATAMATION, February, 1980.

"Design Decisions for the Intelligent Database Machine", by Robert Epstein, Paula Hawthorn in Proceedings of the 1980 NCC, June, 1980.

1.8 General System Description

One unique aspect of this system is that it supplies a very high-level interface to databases for one or more host systems. The IDM is thus a Backend System that is designed to free the host resources which would otherwise be consumed by the Database Management System.

2. DATABASE CONSTITUENTS

2.1 General Description

The constituents of an IDM database are:

Database
Relation
View
Tuple
Attribute

These constituents are related as follows: A database consists of relations of possibly different types. A relation consists of tuples of identical types. A view is a relation derived from one or more relations by relational calculus operations. A tuple consists of attribute values of possible different types. An attribute consists of values from one domain type. The domain type is one of a fixed set of system provided domain types. The user does not explicitly define domains independent of the attributes.

2.2 Detailed Description

2.2.1 Database Structure

An IDM database is named at database creation time. Relations and views are added and deleted to an 'open' database at any time. Database names are up to 12 characters long.

2.2.2 Database Operations

Databases can be created, opened, closed, destroyed, dumped and loaded.

2.2.3 Constraints

The creator of a database is declared the database administrator and only she can destroy the database. It is the responsibility of the host to determine and govern who can create a database.

2.3 Relation

2.3.1 Relation Structure

A relation is viewed as a set of n-tuples and is defined by naming the n attributes and specifying their types and lengths. Duplicate tuples are surpressed on any relation having a suitable access method. It was deemed too expensive to surpress duplicates on completely 'unstructured' relations. Attribute order is not significant. Aliases are defined through views.

2.3.2 Relation Operations

Relations can be created, destroyed, indexed, dumped, loaded and audited.

Predicate calculus operations are supported. The basic IDL command for manipulating relations is in the form:

Command Relation (target-list) qualification.

Commands include:

APPEND - to add tuples to a relation

RETRIEVE - to retrieve tuples into the host

RETRIEVE INTO - to create and add tuples to a new relation

DELETE - to delete tuples from a relation

REPLACE - to replace attribute values in tuples of a relation

The target-list defines, by name, the attributes (or expressions) of the relation. The qualification determines which tuples are to be effected by the command.

In the target-list or qualification, all attribute names must be preceded by a 'tuple variable' which ranges over one relation (or view). The tuple variable, say t, is bound to a relation before each command by:

Range of t is relation_name.

Note that within one command a relation can have more than one associated tuple variable. (Recall that all of these commands are sent to the IDM by a sequence of <token, value(s)> pairs. More details on the qualification and commands are found in Section 3.

2.3.3 Constraints

Sets of attributes can be declared to form a unique key for a relation. A relation can have several unique keys. Protection commands, PERMIT and DENY allow the owner of a relation to specify which commands other users can apply to the relation. PERMIT and DENY allow a predicate calculus qualification to specify the set of tuples of the relation that can be operated on. A target-list can also be specified to limit or allow privileges on various columns.

2.4 Views

2.4.1 View Structuring

A user can issue a:

DEFINE VIEW name (target-list) qualification

to define a view. These views are dynamic in nature in that the view will reflect changes made to the base relations. Keys cannot be defined for views.

A user can issue a:

RETRIEVE INTO name (target-list) qualification

to create a new relation called name. Name is in effect a static view.

2.4.2 View Operations

The same operations that apply to relations can be defined for views including the permit and deny protection operations. There are restrictions on the updating of views.

2.4.3 Constraints

Update operations, APPEND, DELETE, REPLACE can only be applied to a view if the update would only affect one base relation and the effect on the relation can be uniquely determined.

2.4.4 Additional Properties of Views

The IDM allows the user to make a brief statement on the use of views in conceptual modeling.

2.5 Tuple

2.5.1 Tuple Structure

A tuple value is described as an instance of a record in the relation. The definition of a tuple is implicitely defined when the relation is defined. The values in an initial creation of a tuple are determined by the target-list. Values of individual attributes of a tuple can be changed by the replace operator.

2.5.2 Tuple Operations

IDM does support a tuple at a time protocol for a programming language interface running on the host machine. However, for the most part, the tuple at time flow control is considered a buffering problem for the host. The IDM software reference manual does describe how an OEM user can build such an interface.

2.5.3 Tuple Constraints

All tuples must be requested 'associatively' by requesting specific attribute value clauses in the qualification. If an ordering is required, an 'ORDER BY' clause can be stated on a RETRIEVE command and the tuples are returned to the host in the desired order.

In order to declare a 'key' unique, the key must in fact be a physical clustering or non-clustering index. This restriction was based on the feasibility of supporting the uniqueness of a key without such an index.

2.6 Attribute Structure

2.6.1 Attribute Structure

An attribute is defined when a relation is created by specifying its name type and length. The type is restricted to the primary data types supported by IDM. Types include bit string, integer, floating point, packed (zoned) deciman, and character strings.

2.6.2 Attribute Operators

Attributes can be compared with each other through the normal comparison operators $<, \leq, =, \geq, >, \neq$. Arithmetic operators +, -, ÷, x can be used on numeric attributes; string manipulation operators can be used on string attributes. Coercions are made between the different types and lengths of numeric attributes. Specific

coercion functions are also provided for numeric to character and character to numeric conversions. Aggregate functions are supported and are described in detail in Section 3.4.3. Note that these operations can be used to create new attributes in either static or dynamic views.

2.6.3 Attribute Constraints

Floating point operations are not fully supported. The difficulty faced by IDM was in translating different hosts floating point representations into a representation usable by the IDM hardware.

2.6.4 Additional Properties of Attributes

The user can associate descriptive text with each attribute of each relation. A brief statement can be made on the use of attributes in conceptual modeling.

2.7 Domain

Domains are not explicitly defined by IDM.

2.8 Additional Database Constituents.

IDM supports:

Transactions - Transactions are used as a unit of concurrency control and recovery for IDM commands. The user surrounds a set of IDM commands with Begin and End transaction commands. If those are omitted, a single IDM command is treated as a transaction.

Stored Commands - Commands can be stored in the IDM and invoked with different parameters. Use of this feature is suggested for semantic integrity assertion checks and for triggers.

Data Dictionary - The user can access the system relations to store and retrieve constituents of a data dictionary.

Relation Logging - A user can request that a log be maintained of all atomic changes to specified relations. This log can be queried using the retrieval operations.

3. FUNCTIONAL CAPABILITIES

The general format of an IDM command is:

Command Relation (target-list) qualification.

This command is described in Section 2.3.2. Note that the same qualification power is allowed for retrievals and alterations.

3.1 Qualification

Qualification is basically through a calculus oriented approach. The results of a qualification can be thought of as a relation consisting of tuples composed of tuples from one or more relations for which the qualification is true.

3.1.1 Restriction

The simple comparison operators ($<$, $\leq$, $=$, $\geq$, $\neq$) are supported for comparing 'attribute expressions' to 'attribute expressions'. An attribute expression can be a simple constant, an attribute name, or a string or arithmetic expression involving attributes and/or constants. In addition, the arithmetic expression can include the aggregate functions described in Section 3.4.2. The coercion rules were specified in Section 2.6.2.

The simple selection conditions can be combined into more general boolean expressions by ands/ors and nots.

Note that, PROJECTS are implicitly defined through the use of an attribute name either in the qualification or the target list.

As a simple example, consider the qualification

where P.color = "red"

which could select red parts from the parts relation.

3.1.2 Quantification

Existential quantification is supported implicitly or explicitly through an 'any' operator.

For example:

where ANY (P.color = "red") > 0

will be considered 'TRUE' if at least one Part is Red.

Similarly,

where SP.P# = P.P# and P.color = "red"

will be considered 'TRUE' for one SP tuple if there exists a red part supplied by SP.

Universal quantification is supported through the use of count, and count-by functions.

For example,

where Count (P where P.color = "red") = Count(P)

is true if and only if all parts are red.

3.1.3 Set Operations

Being a calculus oriented language, IDL does not explicitly support the set operations. However, intersection and set differences can be done by including the appropriate joining clause in the qualification. Similarly, a cartesion product can

be found by including attributes of different relations in the target list with no corresponding joining clause. Also note that a two relation union operation can be realized by an append operation.

3.1.4 Joining

Equi-joins and natural joins and combinations are all permitted. Up to 15 relations can be joined in one command. No access path restrictions are placed on the attributes to be joined. The coercion rules for attributes can be used to compare different lengths and types of numeric attributes and different lengths of character attributes. In fact, the joining clause can compare an attribute expression to an attribute expression. A relation can be joined to itself by having another 'range' variable pass over the relation.

For example:

where SP.S# = S.S# and SP.P# = P.P#

joins the supply, supplier and parts relations.

3.1.5 Nesting and Closure

The restriction, quantification, most set operations, aggregate functions, and joining are all closed in that the results of those operations can be nested and used in other commands. Examples have already been provided showing the nesting of 'count' and a 'where clause'.

Note that the UNION operation cannot be nested. The system is considered relationally complete.

3.2 Retrieval and Presentation

3.2.1 Database Queries

Queries using IDL notation are expressed through the:

Retrieve (target-list) qualification command.

The results of a retrieval operation appear as a relation containing just the attributes specified in the target list. The full range of qualifications described in 3.1 can be used. The target list can consist of a list of attribute names from possibly different relations, or new attribute names set equal to an expression. The expression can contain aggregate functions, constants or attribute names.

For example,

Retrieve (SP.S#, total = Sum (SP.QOH by SP.S#))

An optional order by clause can be used to control the order in which tuples are returned to the host from the IDM. The order by clause can include attribute names, attribute expressions of attributes in or not in the target list.

3.2.2 Retrieval of Information about Database Constituents

The database schema is stored in 'system' relations and can be queried and retrieved just like normal user relations. Thus, the results of schema queries can be intermixed with database queries. In addition, IDM supports a 'description' relation which contains user defined descriptions of relations/attributes. Note that names of relations, attributes and views are stored in user readable form. Other system information, however, is stored in machine readable form. IDM does allow the user to

store the text of user type definition of a veiw and/or stored commands.

3.2.3 Retrieval of System Performance Data

All system performance data is also stored in 'system' relations. Thus the database qualification and retrieval facilities can be used to monitor disk usage, find information about indices, etc.

3.2.4 Report Generation

Report formating is considered the responsibility of the host system.

3.2.5 Constraint and Limitations

PERMIT and DENY commands can be used to control retrieval permissions to relations and views.

3.3 Alteration

3.3.1 Insert Facilities

The basic insert operation of IDM is to 'APPEND' tuples into an existing relation. Since the system tables are also relations, APPENDs could be used to alter the schema. In general, such use of the system tables as relations is not recommanded. Alternately, a 'block' COPY facility is supported which allows the user to add tuples to a relation from a file outside the data base. IDM informs the host of type violations and if some 'unique key' constraints have been violated in inserting tuples either through an APPEND or a COPY.

Tuples generated during the qualification section can be inserted into a relation through the 'APPEND' operator.

Examples

1) APPEND COMPONENTS (MAJOR = 16, MINOR = 15)

adds one tuple to the components relation. Note that columns

not mentioned in the target list get system defined defaults (o for numeric types, blank for character types).

2. RANGE OF N IS NEWPARTS

   APPEND PARTS (P# = N.P#,...) where N.COLOR = "RED"

   adds all red parts in NEWPARTS to the parts relation.

3.3.2 Delete Facilities

Tuples can be deleted from a relation, and relations can be deleted from a database. To delete tuples from a relation Part:

```
Range of P is Part
delete p [where qualification]
```

The particular tuple deleted from parts depends on the qualification. To delete a relation from the database:

Destroy relation_name. This destroys all indexes, and attribute entries for the relation.

Alternately:

```
Range of r is relation
delete r where qualification
```

can be used. This command will not delete the attribute entries. Note that the user must first destroy the views which reference this relation.

3.3.3 Modify Facilities

Attributes of existing tuples in a relation can be modified by means of the 'replace' operation.

```
Range of u is update_parts
Range p is parts
Replace p (color = U.color) where p.p# = u.p#
```

updates the color attribute in parts for each tuple that has a corresponding tuple in update_parts.

Protection constraint violations are not allowed. Note that the user is not informed that he/she has made a protection violation. Instead the user is simply told that a relation or attribute does not exist. Unique key restraint violations are reported to the host and not allowed. Note that the system relations can also be modified through the REPLACE operation. Such operations can be used to change relation or attribute names.

3.3.4 Commit and Undo

These operations are supported. A user issues a 'Begin Transaction' command. The user (and only the user) can see the results of his or her alterations. If the user issues an 'End Transaction' command, the results are committed. If the user issues an 'Abort', the results are undone. Note that changes to the system catalogues are not undone.

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

The standard arithmetic operations (+, -, *, /, modulo) are supported for numeric types. Concatination, substring operations are supported for character string types. In addition, 'wildcard' searching for string patterns within a field are supported.

3.4.2 Sorting

The user can specify an 'ORDER BY' clause stating sorting requirements on attributes of tuples which are sent to the host system. The relation itself is not guaranteed to be kept ordered by any particular attributes.

3.4.3 Library Functions

MAX, MIN, SUM, COUNT, AVERAGE are all supported. These functions

can be combined with the Group by operation and general qualification. To only include unique values in a SUM, COUNT, or AVERAGE is also supported.

For example:

Range of e is employee

1) Retrieve (ave = avg(e.salary)

   returns the average salary of all the employees.

2) Retrieve (ave = avg(e.salary by e.dept),e.dept)

   returns the average salary of employees for each department.

3) Retrieve (ave = avg(e.salary by e.dept where e.age > 30),e.dept)

   returns the average salary of employees over 30 for each department.

Note that the library group by operators can be used in qualification, retrieval, and alteration.

3.4.4 User Defined Functions

Not supported.

3.4.5 Transactions

Transactions are supported for concurrency control and recovery purposes. See Section 3.3.4.

3.4.6 Multi-tuple Alterations

This function is supported. See Section 3.3.3.

3.4.7 Grouping

Grouping is supported. See Section 3.4.3 for examples.

3.4.8 Exception Handling Mechanisms

IDM allows the user to specify for each command the actions to be taken on the following exception conditions: violation of a

unique index constraint, overflow, underflow and divide by zero. For each condition, a command can be either completely rejected or allowed to continue. If the command continues, status bits indicating that the exception condition had occurred are still returned to the user.

3.4.9 Additional Functional Capabilities

The IDM will store a sequence of parameterized commands. Use of this feature is designed to be used for semantic integrity, assertion checks and for implementing triggers.

4. DEFINITION, GENERATION AND ADMINISTRATION FACILITIES.

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

Database

Relations/Attributes

Views

Indexes/Unique Keys

Relation Descriptions

Attribute Descriptions

Protection Constraints

4.1.2 Database Definition

Create database name. The creator of the database defaults to the database administrator.

4.1.3 Relation Definition

```
Create relation name (attribute_names = type,
                                     .
                                     .
                                     .
                      attribute_names = type)
```

A maximum of 250 attributes per relation are allowed.

A maximum of 32,000 relations are allowed.

Properties such as disk locations and sizes for relations and auditing requirements can be specified here.

4.1.4 View Definition

Define view name (target-list) qualification.

4.1.5 Tuple Definition

Tuple types are defined in the relation definition, see 4.1.3. Tuple instances are defined during qualification, retrieval, and alteration. See Section 3.

4.1.6 Attribute Definition

See Section 4.1.3

4.1.7 Additional Database Constituents

INDEX's can be added or subtracted from relations. At that time, the index key can be declared unique. Note that both clustering and non-clustering indexes can be created. Protection constraints (PERMIT and DENY) can be added to relations.

4.2 Generation Facilities

4.2.1 Constituents of a Database Generation

All of the constituents of a database listed in Section 4.1.1 can be generated during the course of a database application.

4.2.2 Generation of Database Constituents

Database and relations can be dumped to, and loaded from other disks or the host.

4.3 Database Redefinition

4.3.1 Renaming Database Constituents

No explicit facilities are provided for renaming database constituents However, the relational modify operator, REPLACE can be used to replace a relation name or attribute names. For example, the following replace is allowed:

Range of A is attribute

Replace A (name = "colour") where A.name = "color".

4.3.2 Redefining Database Constituents

No explicit facilities are provided for redefining attribute or changing the attributes in a relation. These redefinitions are supported through combinations of retrieve into's and alterations of the database names.

4.4 Database Regeneration and Reorganization

4.4.1 System-Controlled

The system provides monitoring of disk usage and performance. It does not automatically reorganize a database.

4.4.2 DBA-Controlled

The DBA can add and delete clustering and non-clustering indexes to any relations in the database at any time during the application development. Thus indexes can be added before or after a relation is populated. One database can be used to load another database.

4.5 Database Dictionary

A user can store definitions of relations and attribute-relation pairs. The system stores information on the number of attributes, number of tuples of a relation. In addition, the system stores some performance statistics such as disk allocation and usage in a relation.

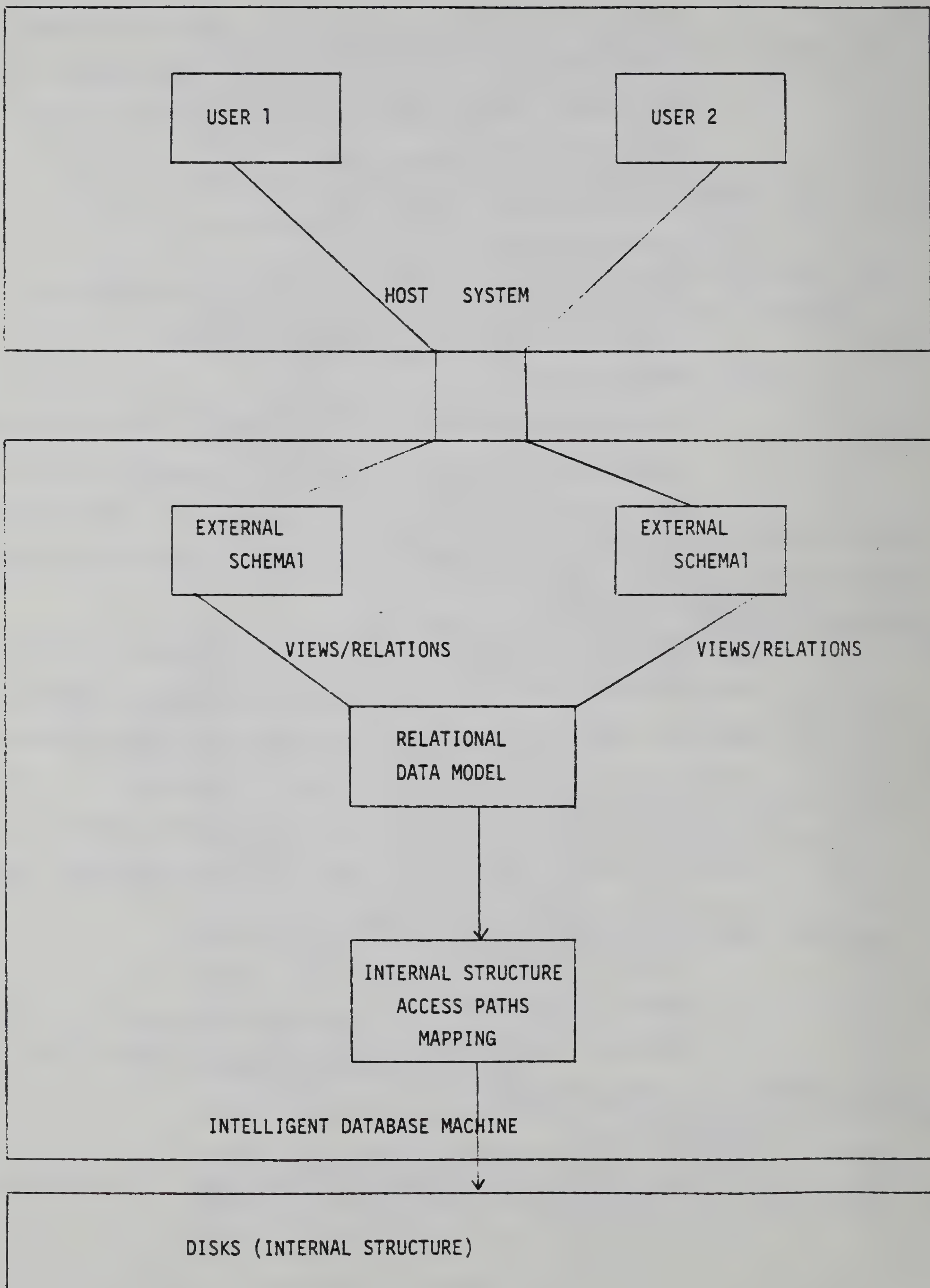
The database language can be used to query any of these relations. For example, to find all relations that have an attribute named social_sec, the following command could be issued:

```
Range of A is ATTRIBUTE
Range of R is RELATION
Retrieve (R.name) where R.RELID = A.RELID and A.name = "SOCIAL_SEC"
```

5. INTERFACE AND DBMS ARCHITECTURE

5.1 System Architecture

The OEM user provides the interface to the human user. The architecture is illustrated below:


USER 1
USER 2
HOST SYSTEM
EXTERNAL SCHEMA1
EXTERNAL SCHEMA1
VIEWS/RELATIONS
VIEWS/RELATIONS
RELATIONAL DATA MODEL
INTERNAL STRUCTURE
ACCESS PATHS
MAPPING
INTELLIGENT DATABASE MACHINE
DISKS (INTERNAL STRUCTURE)

5.2 Interface Descriptions

A single interface is supported. This interface has been described in Sections 2, 3, and 4.

6. OPERATIONAL ASPECTS

6.1 Security

The database administrator (DBA) creates a database and is responsible for assigning security rights. The user authorization is primarily the responsibility of the host system. The IDM does maintain two relations that link users and hosts; and link users to names and groups of users. The DBAs are responsible for providing the data for these relations. The name and groups can be used by the DBA when issuing the PERMIT and DENY commands for particular relations, attributes or parts of relations based on a qualification. (See Section 3.0).

A user can create his/her private relations.

When a relation is created it can be declared 'with logging' and a log of all changes (but not accesses) to that relation will be maintained. The relational calculus commands can be used to query that log.

6.2 Physical Integrity

6.2.1 Concurrency Control

The concurrency control is for the most part transparent to the users. However, the concepts of transactions are supported, allowing a user to issue several IDM commands and preventing other users from seeing these changes until the 'End Transaction' command is given.

Lost updates and phantoms are prevented by providing degree 3 consistency. Since users issue several commands within one transaction, deadlock cannot be completely prevented. However, the chance of deadlock is kept rather small. If deadlock does occur, it is detected and a transaction may be aborted.

6.2.2 Crash Recovery

The IDM is in complete control of the disks and makes extensive efforts to check for physical disk read and write errors; retry the I/O's in case of those errors; and keep track (in relations) of the 'flawed disk sectors'.

The IDM provides for both physical dumping/restoring of disks; and logical dumping/restoring of an entire database or selected relations.

In addition, the audit log can be used to roll forward and make the changes to a restored relation that was created 'with logging'.

In the event of a crash, partially complete transactions can be rolled back to restore the database to a consistent state.

6.3 Operating Environment

The IDM has its own microprocessor and the basics of an operating system that it needs to support database management. The IDM is in complete control of the disks which are attached to it.

Two types of physical interfaces are supported: parallel and serial. Parallel I/O to the IDM is through the standard IEEE-488 bus. The serial interface is through the standard RS232C line.

7. ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS.

7.1 Simplicity/Uniformity

The IDM provides the simplicity of a purely relational model and operations based on the relation calculus. This simplicity is also utilized internally in the maintenance of the data dictionary, indexing information, protection information, stored commands, cross reference information, transaction logging, user identification, and disk allocation and usage.

7.2 Data Independence

The results of the qualification, retrieval and alteration are independent of which access paths and indices which are provided with the exception that the presence or absence of a unique index can affect the results of an IDM command.

7.3 Permits Optimization

Extensive effort is made to automatically optimize the execution of a relation calculus expression. In addition, specialized hardware is used to speed processing.

7.4 Basis for High Level Interfaces/Efficiency

One of the major contentions of the IDM developers is that a database machine must provide a high level interface to effect the communication overhead that would be unavoidable in an attribute or tuple at time database machine.

7.5 Multiple Views of Data

The IDM interface does support multiple views of data.

8. APPLICATIONS

Not yet available.

Feature Analysis of INGRES

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January 1981

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PREFACE

All examples in this feature analysis are based on the database below:

PART

P #	PNAME	WEIGHT	CITY

SUPPLIER

S #	SNAME	STATUS	CITY

SHIPMENT

S #	P #	QTY

[from C. J. Date's An Introduction to Database Systems, 2nd ed., p. 52]

1.0 INTRODUCTION

1.1 Identification

INGRES (Interactive Graphics and Retrieval System). This document is based on version 6.2 with relevant information included from previous versions. Developed by: University of California, Berkeley - Electronics Research Laboratory.

1.2 Status

1.2.1 System

System has been used primarily for teaching and research. Extensive improvement and elaboration to the system has been and continues to be performed.

In the later part of 1980, a company was formed to market INGRES: Relational Technology, Inc., Berkeley, CA.

1.2.2 Applications

INGRES is well suited to a wide variety of applications. For example, application programs written in C may access INGRES databases through the EQUEL interface. Non-programmers who are skilled database users can meet their information management needs by utilizing QUEL, an interactive non-procedural query language. Casual users can quickly and efficiently access databases through CUPID, a pictorial query language (not available for all installations). A generalized geographical data handling subsystem called GEO-QUEL is included in INGRES. It is used for research in the area of urban economics.

1.3 System Background

INGRES is the result of a research project at the University of California, Berkeley. Faculty and students there designed and implemented the system with graphical capabilities and mini-computer architecture in mind.

1.4 Overall Philosophy

The objective of INGRES is to provide a high degree of data independence and a non-procedural facility for data definition, retrieval, update, access control, and integrity verification.

1.5 Essentially Relational Characteristics

INGRES meets all of CODD's (TODS Vol.4, No.4) requirements for the relational database model and therefore may be classified as fully relational. One suggested criterion based upon the power of the relational algebra is not applicable to INGRES since its usage is based upon relational calculus. However, it has been shown that the relational calculus is equivalent to the relational algebra.

1.6 Interfaces

QUEL - General query language for INGRES based upon relational calculus with facilities for data definition, retrieval, update, access control and integrity verification.

EQUEL - Interface which allows the inclusion of QUEL statements in C programs.

CUPID - Nonprocedural pictorial query language designed for the casual user. Includes facilities for retrieval and update.

GEO-QUEL - Interface which provides users the capability of presenting geographic data in map form.

1.7 Documentation

Epstein; "Creating and maintaining a data base using INGRES," ERL technical memorandum M77/72, University of California.

Hawthorne, P.; and Stonebraker, M. "The Use of Technological Advances to Enhance Data Management System Performance, "ERL technical memorandum M79/3, University of California.

Held, C.D.; Stonebaker, M.R.; and Wong, E. "INGRES: A Relational Database System," Proc. ACM Pacific 75 Regional Conf., May 1975, pp. 409-416.

McDonald, N.; and Stonebraker, M. "CUPID: The Friendly Query Language, "Proc. ACM Pacific 75 Regional Conf., April 1975, ACM, New York, 1975, pp. 132-139.

Rowe, L. "INGRES Data Dictionary," memo received 23 January 1981.

Stonebraker, M. "Concurrency Control and Consistency of Multiple Copies of Data in Distributed INGRES," ERL technical memorandum reprint 1702, University of California.

Stonebraker, M.; Wong, E.; Kreps, P.; and Held, C.D. "The Design and Implementation of INGRES," ERL technical memorandum reprint 1468, University of California.

Woodfill, J.; et al. "INGRES Version 6.2 Reference Manual," ERL technical memorandum M79/43, University of California.

1.8 General System Description

INGRES is a relational database management system. A user may access the system interactively through the UNIX command processor. It has several interfaces for data definition and retrieval. Besides interactive use, INGRES facilities are available embedded within a procedural language for batch use.

2.0 DATABASE CONSTITUENTS

2.1 General Description

2.1.1 Feature Catalog Term Translation Table

System Term	Feature Catalog Term
Database	Database
Relation	Relation
View	View
Tuple	Tuple
Attribute	Attribute
Domain	Domain

Note that INGRES does not maintain any functional distinction between attributes and domains. These two terms are often used interchangeably but in this document the terminology will be restricted to the word attribute. Note that this lack of explicit domains does not preclude any theoretical implications arising from the definition of relations from the cartesian product of a set of value domains.

2.2 Database

2.2.1 Database Structure

A database is defined as a time-varying collection of relations.

2.2.2 Database Operations

There are a number of operations implemented in INGRES which are relevant to the database as an RDM constituent:

CREATDB name - Establish a new, initially empty database with the given name. The user who issues the CREATDB command is the owner of the database and is referred to as the DataBase Administrator (DBA). Certain commands related to other RDM constituents are restricted to use by the DBA (e.g. DESTROYDB).

DESTROYDB name - Destroy a database (empty or not). Only the DBA may issue this command.

2.2.3 Database Constraints

The only global assertion which applies to the entire database is the one referred to above, i.e. the distinction between the database owner or DBA and other users. This constraint manifests itself at other constituent levels and will be dealt with in this document when appropriate. There is a system relation known as the USER's file which contains the information specifying which databases can be opened and by whom.

The creation and destruction of databases is tightly coupled to the UNIX operating system. As a result, INGRES enjoys the flexibility, power and security of the UNIX file management system.

2.3 Relation

2.3.1 Relation Structure

A relation is defined as a subset of the cartesian product of N sets of attribute values. It is generally assumed that the user's perception of a relation is an entity over which functions and/or predicates can be evaluated. It is also possible to visualize a relation as a table in which the tuples constitute the rows and the attributes constitute the columns. Duplicate tuples are always removed when relations are updated.

2.3.2 Relation Operations

There are a number of operations available in QUEL which relate to the relation as a database constituent:

CREATE name	-	Create a new relation with the given name. The user issuing the CREATE command is designated as the relation's owner.
COPY	-	Append the data in UNIX file to an existing relation owned by the user.
DESTROY name	-	Delete a named relation from the database.
INDEX	-	Create secondary indices on existing relations
MODIFY	_	Define the storage structure for a relation by specifying storage organization and keys
PRINT name	-	Print the entire contents of a relation.
SAVE	-	Change the default relation expiration date.

2.3.3 Relation Constraints

Relation operations may be issued only by the owner of a relation (i.e., the user who CREATEs the relation).

2.3.4 Additional Properties of Relations

None found.

2.4 Views

2.4.1 View Structure

Views are defined as a set of dynamically derived relations. A view structure is essentially a relation structure which has its operations restricted. Statically derived relations are defined in a different manner. The keys of a view are inherited from the base relation definition.

2.4.2 View Operations

Views are defined from relations in the database by the use of the QUEL DEFINE command. View definition can be specified as a subset of the values in the base relation by means of a qualification statement identical to those used in retrieval commands. No other form of view manipulation is possible.

All forms of retrieval on the view are fully supported

```
e.g.,  range of p is part
       range of s is supplier
       define view parsup (parnan = p.pname, pnum = p.p#,
pstat = s.status) where p.city = s.city
```

2.4.3 View Constraints

Although views are directly derived from relations, they cannot be manipulated as relations can be.

Updates are supported if and only if it can be guaranteed that the result of updating the view is identical to that of updating the corresponding real relation.

The person who defines a view must own all relations upon which the view is bused.

2.4.4 Additional Properties of Views

None found.

2.5 Tuple

2.5.1 Tuple Structure

A tuple is an instance of a relation. It is implicity defined when the relation is created. Keys are defined at the relation level and only for purposes of storage structures.

2.5.2 Tuple Operations

There is a wide variety of operations in QUEL for manipulating tuples. Since the query languages for INGRES are based upon the relational calculus, tuples are selected from a relation which is represented by a tuple-variable. A tuple-variable is defined by use of the RANGE statement. Once a tuple-variable is defined, the definition remains in effect until it is redefined or the user ends the QUEL session. Operations for manipulating tuples include:

APPEND	-	Add a tuple or tuples to an existing relation.
DELETE	-	Remove one or more tuples from a relation. Note multi-tuple alteration capability.
REPLACE	-	Modify one or more attribute values in one or more tuples of a relation.
RETRIEVE	-	Retrieve a subset of the tuples from a relation.

Each of these operations can include an optional qualification involving tuple-variables. These qualifications select a subset of the tuples in a relation represented by a tuple-variable.

2.5.3 Tuple Constraints

Tuples may be ordered, but only if the storage structure for the relation has key ordering. When new relations are formed from the retrieval of tuples (or a subset of the attributes of the tuples) duplicates are always removed. Tuples retrieved for display do not have duplicates removed unless the UNIQUE keyword is specified in the RETRIEVE statement. The present system allows a tuple size maximum of 512 bytes with a maximum of 50 attributes.

2.6 Attributes

2.6.1 Attribute Structure

The names and characteristics of attributes are defined when the relation which contains them is defined.

2.6.2 Attribute Operations

Attributes (in conjunction with tuple-variables) can be used in QUEL qualification statements. These attributes are combined in qualification statements with boolean algebra and relational operators as well as implicit existential quantification. The power of the qualification statements is extended by the inclusion of a large library of computational (SIN, COS, SORT, etc.) and aggregation (SUM, COUNT, AVG, etc.) functions.

2.6.3 Attribute Constraints

See Section 2.5.3.

2.7 Domain - INGRES does not distinguish between domains and attributes

2.7.1 Domain Structure

Not Applicable.

2.7.2 Domain Operations

Not Applicable.

2.7.3 Domain Constraints

Not Applicable.

2.8 Additional Database Constraints

None found.

3.0 FUNCTIONAL CAPABILITIES

3.05 General Syntax format for QUEL

RANGE OF (tuple-variable) IS (relation-name) (repeated for each tuple-variable ranging over different relations)

Note: The tuple-variable concept has been found very useful for specifically identifying the relation being referenced. This concept is especially useful when joining relations and in self-join operations.

RETRIEVE (target-list) WHERE qualification

APPEND TO relation-name (attribute-name=value...)

DELETE (tuple-variable) WHERE qualification

REPLACE (tuple-variable) (target-list) WHERE qualification

3.1 Qualification

3.1.1 Restriction

Qualification in QUEL is based upon relational calculus. See section 2.5.2 for a discussion of the role of attributes, tuple-variables and operations involved in qualifications. The following examples demonstrate the flexibility of the WHERE clause:

(a) Simple
WHERE P.COLOR = "BLUE"

(b) Join
WHERE S.S# = SP.S# AND SP.QTY>100

3.1.2 Quantification

Existential quantification is implicit when more than one tuple-variable is present in a qualification statement. Universal quantification is not directly supported but can be implied by the use of the COUNT function.

List the names of all suppliers who supply all parts:

RANGE OF S IS SUPPLIER

RANGE OF SP IS SHIPMENT

RANGE OF P IS PART

RETRIEVE (S.SNAME) WHERE COUNT(SP.S# = S.S# AND SP.P# ! = P#)=0

3.1.3 Set Operations

Not supported.

3.1.4 Joining

QUEL supports the join operation in relational calculus. See Section 3.1.1 (b) for an example.

3.1.5 Nesting & Closure

The optional [into resultname] clause allows the result to be created as a relation.

3.1.6 Additional Aspects of Qualification

None found.

3.2 Retrieval and Presentation

3.2.1 Database Queries

Queries in QUEL are almost entirely composed of qualification and so require no further discussion. However, CUPID is so different in how qualifications are formed, it is worth mentioning here. The relationship between attributes is implied by pictorial constructs.

3.2.2 Retrieval of Information about Database Constituents

The special relations known as Relation and Attribute contain the information about their respective subjects. INGRES has no single facility known as a data dictionary. The information considered necessary for a data dictionary is contained in the two relations already mentioned, plus four additional relations: INDEXES, PROTECT, INTEGRITIES and TREE. The six relations are called system relations or system catalogs and will be described in Section 4.5.

3.2.3 Retrieval and System Performance Data

No known.

3.2.4 Report Generation

No known.

3.2.5 Constraints and Limitations

CUPID is restricted to retrieval and update only. Restrictions on which relations may have tuples retrieved or altered can be defined by the owners of the relation. This feature is discussed further in section 6.1, Security.

3.2.6 Additional Aspects of Retrieval and Presentation

Data can be retrieved in order to construct ordinary UNIX files.

3.3 Alteration

3.3.1 Insert Facilities

Relations can be altered by appending new tuples. If any views are based upon altered relations, they too are subsequently modified.

Add a new part to the PART relation:

```
APPEND TO PART (P#=P5,PNAME="WIDGET",COLOR="GRAY",WEIGHT=50,CITY="TAMPA")
```

3.3.2 Delete Facilities

Tuples may be deleted from a relation

Remove all suppliers located in Paris from the SUPPLIER relation:

```
RANGE OF S IS SUPPLIER

DELETE S WHERE S.CITY = "PARIS"
```

3.3.3 Modify Facilities

Tuples in a relation may be replaced by new tuple values.

All green bolts are now manufactured with a blue color. Update the PART relation to reflect this change in specifications:

```
RANGE OF P IS PART

REPLACE P (P.COLOR="BLUE")

 WHERE P.NAME="BOLT"ANDP.COLOR="GREEN"
```

3.3.4 Commit and Undo Facilities

None found.

3.3.5 Additional Alteration Facilities

No additional features found.

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

Arithmetic operations supported by QUEL are: addition, subtraction, multiplication, division and exponentiation.

3.4.2 Sorting

Ordering is specified for a relation when the keys for a storage structure are specified.

3.4.3 Library Functions

QUEL supports MIN, MAX, AVG, SUM, COUNT, COS, SIN, ATAN, LOG, RAND, SQRT, MOD and GAMMA library functions. Each function has a definition which is obvious from its name.

3.4.4 User Defined Functions

A terminal monitor macrofacility is included to help users tailor the QUEL language. The macro facility performs text substitution and can invoke built-in macros.

3.4.5 Transactions

No transaction facilities are available.

3.4.6 Multi-Tuple Alterations

Multi-tuple alterations are supported.

3.4.7 Grouping

Grouping is implicitly or explicitly performed by the use of the aggregation functions.

e.g. - implicit
Find the sum of all quantities of supplied parts whose color is blue.

```
RANGE OF SP IS SHIPMENT
RANGE OF P IS PART

RETRIEVE (P.PNAME,QSUM=SUM(SP.QTY))
  WHERE SP.P# AND P.COLOR = "BLUE"
```

e.g. - explicit
Find the average quantity by supplier #

```
RANGE OF SP IS SHIPMENT

RETRIEVE (AVQTY = AVG(SP.QTY by SP.S#))
```

4.0 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

A database is define by means of the CREATDB command.

e.g. CREATDB name establishes a new, initially empty database with the name provided by the user.

4.1.2 Database Definition

In accordance with 4.1.1, the definition of a database with the name SUPPLIES would be accomplished by:

CREATDB SUPPLIES

The database SUPPLIES is owned by the user who initiates the CREATDB command.

4.1.3 Relation Definition

To define the relations for a given database, one uses the CREATE command.

Defining the relations, their attribute names and formats for the SUPPLIES database would be:

```
CREATE PART (P#=i2,PNAME=c10,STATUS=i2,CITY=c10)
CREATE SUPPLIER (S#=i2,SNAME=c10,STATUS=i2,CITY=c10)
CREATE SHIPMENT (S#=i2,P#=i2,QTY=i2)
```

The attributes are defined wit-in the parentheses. This subdefinition is discussed in 4.1.6.

4.1.4 View Definition

Views may be created dynamically with the DEFINE VIEW command. To define a view of the SUPPLIER relation such that the access is limited to tuples whose city is London:

```
RANGE OF S IS SUPPLIER
DEFINE VIEW LONDON-SUPPLIER
     (SUPPLIER) WHERE S.CITY = "LONDON"
```

4.1.5 Tuple Definition

Tuples are implicityly defined at the same time the relation is defined.

4.1.6 Attribute Definition

Attributes are defined while relations are defined. As noted in 4.1.3, attribute definition takes place within parenthesis. The form of this definition is:

attribute name = format

The format represents the data type and number of bytes of storage needed. For example, i2 represents two bytes of integer data and c10 means ten bytes of character data.

4.1.7 Domain Definition

None

4.1.8 Definition of Additional Database Constituents

A user may define an integrity constraint via:

DEFINE INTEGRITY on relation-name is qualification

A user may also define permission for a relation by means of:

DEFINE PERMIT retrieve, replace, delete, append or all
ON rel-name TO login-name [special times] [WHERE qualification]

4.2 Generation Facilities

4.2.1 Constituents of Database Generation

The database is populated by APPENDing or COPYing tuples into relations.

4.2.2 Generation of Database Constituents

Base relations are generated by the user explicitly, while derived relations are generated automatically.

4.3 Database Redefinition

4.3.1 Renaming Database Constituents

No known facilities for renaming other than redefining and copying.

4.3.2 Redefining Constituents

There is no known redefiniton capability for a database in general. DEFINE VIEW or the storage structures of the relation may be redefined via MODIFY.

Tuples may be redefined by APPENDing (to add, DELETEing (to delete).

Attribute values may be redefined with the REPLACE command.

4.4 Database Regeneration and Reorganization

4.4.1 System Controlled

Database reorganizations performed automatically by the system include only those techniques provided by UNIX. If a relation has a secondary index and the primary relation changes, the secondary one is automatically updated.

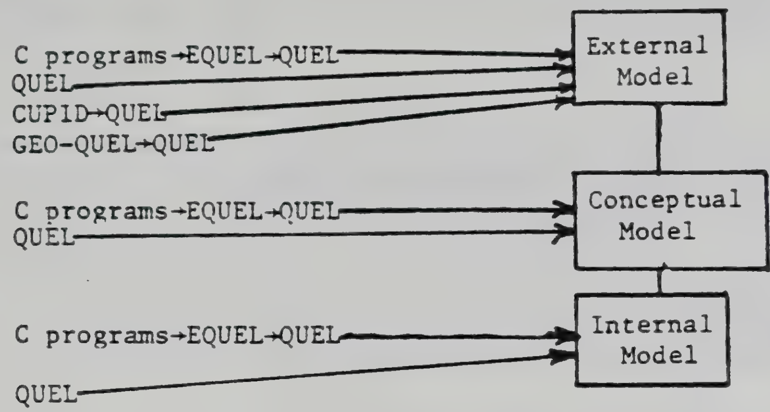
4.4.2 DBA-controlled

There are few special DBA functions. Typically, however, the DBA would CREATEDB and become the owner. Owner's of databases and relations have the special operation of MODIFY which allows them to change the storage structure of a relation (dynamic storage restructuring).

Anyone has the ability to create a secondary index via INDEX command.

5.0 INTERFACES AND DBMS ARCHITECTURE

5.1 System Architecture



5.2 Interface Descriptions

5.2.1 QUEL

The purpose of QUEL is to provide skilled database users who are non-programmers with a non-procedural interface to INGRES. QUEL supports a wide range of diverse functions including many especially designed for use by a DBA. QUEL is a linear relational calculus-based, stand-alone language.

The use of QUEL is clearly elucidated in sections 3.1.2, 3.3.1, 3.3.2, 3.3.3 and 4.1. Refer to the sections for examples of QUEL commands.

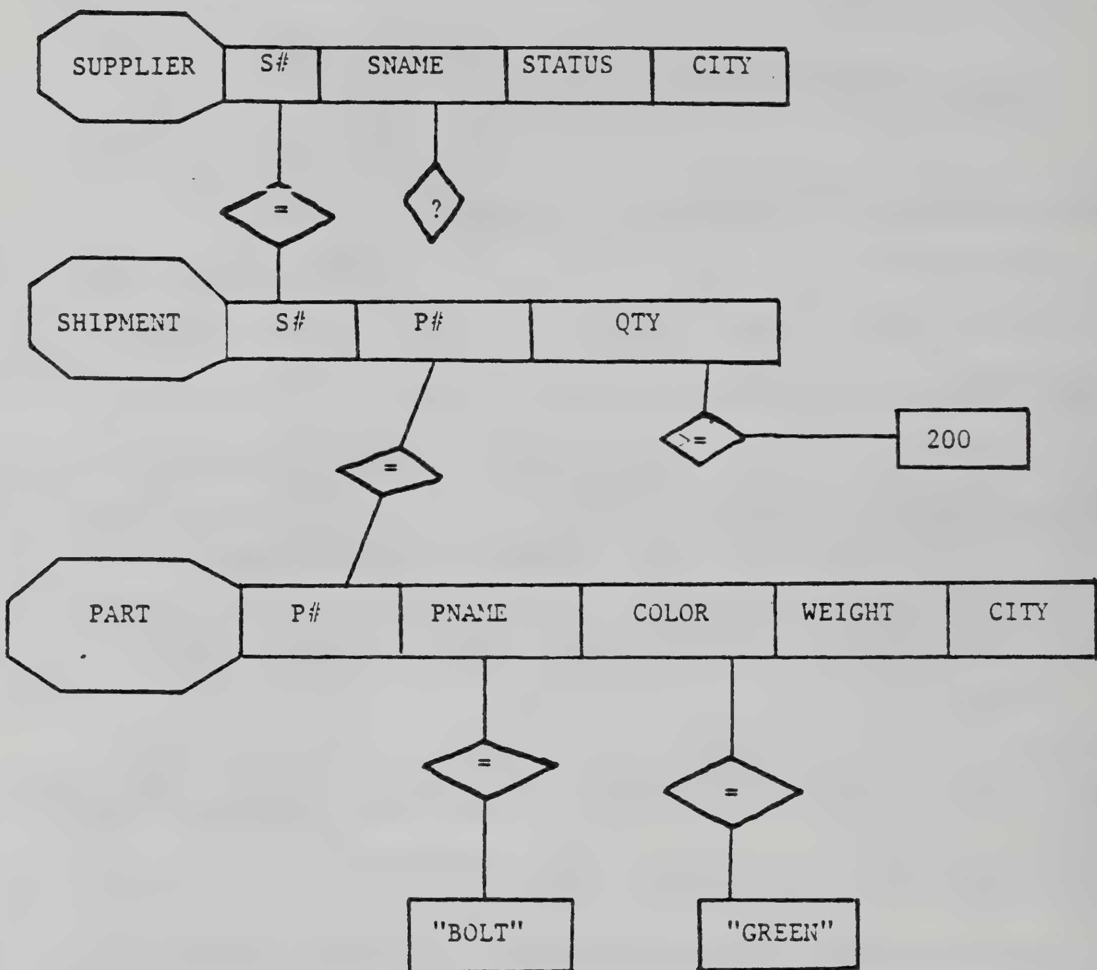
5.2.2 EQUEL

The C programming language interface to QUEL and INGRES. EQUEL allows tuple at a time retrieval. All binding of variables to database objects is performed at run-time.

5.2.3 CUPID

A pictorial query language designed for casual users. The selective powers of CUPID is equivalent to the relational calculus. The language is highly interactive (utilizes light pen) and designed strictly for interactive use.

We will present an example of retrieval using CUPID. The query answers the question "List the names of all suppliers who supply green bolts in quantities of 200 or more."



5.2.4 GEO-QUEL

Geographical data interface to INGRES. Contains extensive graphical capabilities including map presentation of appropriate data.

6.0 OPERATIONAL ASPECTS

6.1 Security

6.1.1 Access Control

INGRES provides a high-level of access control through the QUEL DEFINE PERMIT command. This command may be issued by the relation's owner in order to restrict access by other users to the relation and/or attributes of the relation. This command is very flexible because it also allows restriction of the type of operation which may be performed (retrieval, update, etc.) as well as time and date of access constraints. Data dependent access control is supported since the PERMIT command allows a qualification to be specified which restricts access to a subset of a relation's tuples.

6.2 Physical Integrity

6.2.1 Concurrency Control

INGRES can support concurrent update at the discretion of the DBA. It uses a preclaim algorithm to avoid deadlock. The locking granularity is at the relation level but has the capability of working at the page level.

6.2.2 Crash Recovery

A UNIX level command provides support for recovery from system failures. a QUEL command and a UNIX level command allow the creation of backup files.

The DBA may run the RESTORE command to recover from an INGRES or UNIX crash.

6.3 Operating Environment

6.3.1 Operating System

INGRES requires UNIX to provide file management and security. INGRES is written in C and therefore requires a C compiler.

6.3.2 Hardware Environment

INGRES operates on PDP-11 architectures. Database sizes are unlimited, but individual relations can be no larger than the maximum UNIX file size.

7.0 ESSENTIALLY RELIATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS

As a fully relational RDM INGRES clearly provides the following advantages which are generally accepted as solutions to generalized DBMS problems:

7.1 Simplicity

INGRES interfaces are based upon highly usable extensions to the relational calculus. As a result, a small uniform set of operations provides a wide range of selective power.

7.2 Uniformity

As the basis for INGRES operations, the relational calculus exhibits closure. Closure is a desirable property which simplifies user interaction with the database.

7.3 Data Independence

As a fully relational DBMS, INGRES provides a high degree of data independence.

7.4 Permits Optimization

INGRES research has led to a technique of query processing known as decomposition. This technique facilitates query optimization. Also, data from storage structure details allows the storage structures to be optimized. This optimization can lead to faster response times for commonly used retrieval specifications.

7.5 Basis for High Level Interfaces

The data independence, simplicity and uniformity of INGRES data representation and operations makes high level interfaces possible and practical.

7.6 Natural

There is little evidence to indicate that any one data model is particularly suited to the structural aspects of certain applications. Most of the literature in this area is based upon opinion, not experimental facts.

7.7 Efficient Storage and Retrieval Potential

While there is nothing in the relational model which precludes its implementation on a data base machine, the same may be said of other data models. The research of David Hsiao and Associates at the Ohio State University is particularly relevant to this topic.

7.8 Multiple views of data

The INGRES relational model does provide a flexible and highly usable method for defining view structures. (However, it would be unwise to state that this is an exclusive capability of RDMs. Note the highly developed subschema capability of the CODASYL (network) model.)

7.9 Advantages for Distributed Databases

INGRES has recently been extended to support distributed databases. However, since distributed databases are an actively on going research topic, it would seem premature to claim RDM's superiority in this area.

7.10 Security

Security seems to be a distinct advantage to RDMs since the access control rules can be stated using the same techniques as other operations (e.g. retrieval and update). This is further evidence of the simplicity of the relational model.

8.0 DATABASE APPLICATIONS USING THE SYSTEM

INGRES has been used for a variety of generalized DBMS applications in industrial, academic and governmental situations. In particular the New York telephone company has utilized INGRES for maintaining a database relating to phone line utilization, reliability and performance. GEO-QUEL has been used at Berkeley for urban economic analysis. At present (8/80), perhaps the most sophisticated edition of INGRES is being used for the Department of Energy's Energy Storage database at Lawrence Livermore National laboratory. This system uses a PDP 11/70 with 4M byte memory. Both numerical and bibliographic databases are stored in the schema. The laboratory has implemented a browsing data dictionary capability with self-prompting facilities on top of INGRES. A VAX/VMS version of INGRES has been developed and is marketed by Relational Technology, Inc.

MRDS/LINUS
System Evaluation

by
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November 1980

1.0 INTRODUCTION

1.1 IDENTIFICATION

Multics Relational Data Store (MRDS) is a programming language oriented relational Data Base Management System (DBMS). The Logical Inquiry and Update System (LINUS) is an on-line query and update interface to MRDS.

1.2 STATUS

1.2.1 System

MRDS/LINUS is commercially available as unbundled software on the Honeywell Information Systems Series 60, Level 68 (Multics).

1.2.2 Applications

MRDS is designed to support application programs accessing small to large size data bases.

LINUS is designed to support interactive access to MRDS data bases.

1.3 SYSTEM BACKGROUND

MRDS came into being as a result of the need for a general purpose data base management system for the Honeywell Multics operating system. It owes much to DSL-Alpha. It was first released as a commercial product in 1975.

LINUS drew heavily upon the SEQUEL language and was first released commercially in 1977.

MRDS and LINUS are written in PL/I.

1.4 OVERALL PHILOSOPHY

MRDS provides a relational data base management system for application programs. It frees application programmers from being concerned with data storage structures and allows non-procedural access to data. It provides a high degree of program independence from the data storage structures because of its use of the data submodel. It also serves as a "tool" for the development of interactive end user facilities, such as LINUS.

LINUS provides users with an easy-to-use, mapping oriented, interactive interface to relational databases. It is built "on top of" MRDS.

1.5 ESSENTIALLY RELATIONAL CHARACTERISTICS

MRDS and LINUS are fully relational. They support the structural aspects of the relational model, including the domain concept. They support insert, update and delete operations. They both support data sublanguages which are at least as powerful as the relational algebra. The only restriction on the join attributes is that they must be union compatible. The relations have no access path dependencies. There are no index dependencies for database access, nor are there any built in insert, update or delete dependencies. The qualification principles are high-level and set-oriented. Relations may be derived from one or more existing relations, and constraints can be added to domain definitions during the lifetime of an application.

1.6 The interfaces to MRDS/LINUS provide the following capabilities:

- data base schema definition including constraint definition.
- programming language-level querying and modification of the data base.
- data base creation and generation.
- interactive querying and modification of the data base.
- definition of data base views.
- administrative utilities to monitor data base activity
- definition of secondary indexes.

1.7 DOCUMENTATION

Honeywell Information Systems. Series 60 (Level 68). Logical Inquiry and Update System (LINUS) Reference Manual. Order Number AZ49. Honeywell Information Systems, 200 Smith Street, Waltham, Massacusetts, 1980.

Honeywell Information Systems. Series 60 (Level 68). Multics Relational Data Store (MRDS) Reference Manual. Order Number AW53. Honeywell Information Systems, 200 Smith Street, Waltham, Massachusetts, 1980.

Weeldryer, J.A. and Friesen, O.D., "Multics Relational Data Store: an implementation of a relational data base manager," in Proc. Eleventh Hawaii International Conference on Systems Sciences, Jan. 1978, Vol. 1, pp. 52-66.

1.8 GENERAL SYSTEM DESCRIPTION

(See 1.6)

2.0 DATABASE CONSTITUENTS

2.1 GENERAL DESCRIPTION

The constituents of an MRDS database are:

- database
- relation
- tuple
- attribute
- attribute name
- domain
- data model
- data submodel (=view)
- temporary relation (=view)

These constituents are related as follows: An MRDS database consists of relations of possibly different types. A relation consists of tuples of identical type. A temporary relation is a snapshot view derived from one or more relations by means of qualification operations. A data model provides a global definition of the data base. A data submodel provides a view of a subset of the data base and its relations allowing for synonym references to the relation names and attributes names. A tuple consists of an ordered set of values of attributes. Attributes are defined over a domain. A domain is a user-defined data type.

The constituents of a LINUS database are related to the MRDS constituents as follows:

MRDS	LINUS
database	(same)
relation	table
tuple	row
attribute	column
domain	(same)
data model	(same)
data submodel	(same)
temporary relation	temporary table

2.2 DATABASE

2.2.1 Database Structure

The database structure consists of a Multics directory and a number of subordinate entries:

- database control file
- data model file
- a file model definition file for each file created
- a keyed sequential file for each (base) relation created.

Note: Currently, a file must contain one (base) relation.

The database control file contains running information related to usage of a database and concurrent access control.

The data model file contains schema-like information about the database, files, relations, attributes and domains.

The file model segments contain information about how the relations are arranged in each file.

Optionally, a number of data submodels may be created for each database. The submodels define a subset view of the data model for the user. The data submodel allows attibutes to be given different names and to be reordered within their containing relations. It also allows the renaming of relations. (It does not allow relations to be joined.) (See 2.4.)

2.2.2 Database Operations

Some of the operations available for database definition, generation and manipulation are:

- modify the database control files' contents
- display the contents of a data model
- display the contents of a database control file

2.2.3 Database Constraints

Database constraints are defined on the relation and domain level.

2.2.4 Additional Database Properties

(Not Applicable)

2.3 RELATION

2.3.1 Relation Structure

A relation consists of tuples of identical type. An MRDS relation is perceived as a set of tuples, each containing values for the same set of attribute names. Each tuple in a relation is guaranteed to be unique from other tuples in that relation.

Relation and attribute names are fixed. They may be given aliases through use of the Data Submodel mechanism. Attributes within a relation may also be reordered through use of the Data Submodel mechanism.

In LINUS a relation is perceived as a table of rows and columns.

2.3.2 Relation Operations

Operations defined for relations are those for qualifying (see 3.1), querying (see 3.2), altering (see ?.3), arithmetic and string operations (see 3.4.1), standard set functions (see 3.4.3), and user-defined functions (see 3.4.4).

The primary design goal of the MRDS relation operations was to provide a high level relationally complete programming language interface based upon the first order predicate calculus. The operations execute in piped mode allowing the application program to deal with selected relations one tuple at a time in a procedural manner.

The primary design goal of the LINUS relation operations was end-user convenience. In addition to providing the equivalent selection power provided by MRDS, LINUS allows for a more extensive use of set and scalar functions and arithmetic expressions.

The tuples of a relation are not assumed to be ordered.

2.3.3 Relation Constraints

Each relation is required to have at least one attribute designated as the primary key. A primary key may consist of more than one attribute. The value of the primary key must be non-null and serves to uniquely identify each tuple in a relation (i.e., no duplicates allowed). The values of attributes which are components of primary keys cannot be modified. Any attempt to modify a primary key component will result in an error message being returned to the user.

Each attribute named in a relation must be defined by means of an attribute or a domain statement. (The definition of a domain implies the definition of an attribute with a name identical to the domain name.)

2.3.4 Additional Properties of Relations

Although not enforced by the system, it is assumed that the base relationss are normalized.

2.4 VIEWS

2.4.1 View Structure

There are 2 types of views available in MRDS and LINUS: the data submodel and the temporary relation (or temporary table, in LINUS).

2.4.2 View Operations

The data submodel operations are:

- o create the data submodel
- o display the contents
- o open the submodel view
- o close the submodel view

The data submodel allows relations and attributes to be given new names, allows the subsetting of relations and attributes and allow the reordering of attributes within a relation. The data submodel definition is performed as a part of the administrative function and is not a part of the qualification operations. Once defined, a data submodel cannot be modified. Since it exists as a Multics file, it can be deleted using the Multics delete file command. If the data submodel relation contains less attributes than the base relation, it is not possible to use the store and delete operations.

The temporary relation operations are:

- o define and load a temporary relation
- o select data from a temporary relation

Temporary relations are defined using the selection operation at run time. Temporary relations may be created from other temporary relations. The user must specify which selected attributes are to be used as primary key components of the temporary relation being defined. Temporary relations remain in existence only for the duration of the data base session.

Temporary relations cannot be updated.

2.4.3 View Constraints

The constraints definable using data submodels are to provide the user with a subset of the database and to restrict access to database subsets. This is accomplished by assigning access control lists to the data submodel file.

2.4.4 Additional Properties of Views

Data submodels are intended to be used for subsetting and access control purposes.

2.5 TUPLE

2.5.1 Tuple Structure

A tuple is an instance of the values of each of the attributes known to a relation corresponding to a row of a table. Tuples in a base relation are created as a result of the store operation. Each tuple is identifiable by the unique value of its primary key.

2.5.2 Tuple Operations

MRDS operates in piped mode and provides a tuple-level interface. The operations allowed are:

- o store
- o delete
- o retrieve
- o modify

The delete, retrieve and modify operations are used in conjunction with a selection expression or predicate.

2.5.3 Tuple Constraints

Tuples within base relations must be unique and are presumed to be unordered. (Due to implementation considerations, tuples are ordered in ascending sequence on primary key value, but they are still assumed to be unordered.) (See 2.3.2.)

Primary key values cannot be modified. Attempts to do so will generate an error status code.

2.5.4 Additional Properties of Tuples

If a view or a selection expression does not reference the primary key, then it is possible to retrieve duplicate tuples or to eliminate duplicates, at the user's option (see 3.1).

2.6 ATTRIBUTE

2.6.1 Attribute Structure

The attribute is a named component of a relation, corresponding to the column of a table. By default, there exists one attribute name equal to each defined domain name. It is also possible to define multiple attribute names ranging over one domain. Attributes derive their data types and integrity constraints from the associated domain definition. Attribute values must be non-null.

2.6.2 Attribute Operations

The MRDS operations available for manipulating attributes are:

- o logical operators (&, 1,)
- o relational operators (=, =, , , =, =)
- o arithmetic operators (+, -, *, 1)
- o scalar functions (i.e., PL/I builtins: abs, after, before, ceil, concat, floor, index, mod, reverse, round, search, substr, verify, and user-defined functions)

The LINUS attribute (or column) operations include all the MRDS attribute operations in addition to the following set (i.e., aggregation) functions:

- o average
- o count
- o max
- o min
- o sum

2.6.3 Attribute Constraints

Attribute constraints are inherited from the underlying domain constraints (see 2.7.3).

2.6.4 Additional Properties of Attributes

(Not Applicable)

2.7 DOMAIN

2.7.1 Domain Structure

A domain defines the set of all values an attribute value in the database may assume. It provides for the definition of a domain name and the data type the associated data values will conform to on the data base. The data types are defined using PL/I syntax. The supported data types are:

- real fixed binary (short and long)
- real floating binary (short and long)
- complex fixed binary (short and long)
- complex floating binary (short and long)
- real fixed decimal
- real floating decimal
- packed decimal
- complex fixed decimal
- complex floating decimal
- bit string
- varying bit string
- character string
- varying character string

Data types of program data to be stored and of variables into which data is to be retrieved in MRDS application programs need not be the same as the data types of the attributes, underlying domains. Data conversion is performed automatically by MRDS using PL/I conversion rules (see 3.1.1).

2.7.2 Domain Operations

Domains are not directly operated on by MRDS or LINUS except when the database is created.

2.7.3 Domain Constraints

A check procedure may be defined for each domain to verify data integrity prior to storage into the database.

Encoding and decoding procedures may also be defined for each domain to convert data values upon storage into or retrieval from the database.

2.7.4 Additional Properties of Domains

(Not Applicable)

2.8 ADDITIONAL DATABASE CONSTITUENTS

(Not Applicable)

3.0 FUNCTIONAL CAPABILITIES

3.1 QUALIFICATION

In MRDS the selection expression is calculus oriented and consists of 3 clauses:

- the range-clause
- the select-clause
- the where-clause

The range-clause allows the user to assign a tuple variable to each relation to be referenced.

The select-clause allows the user to define those tuple attributes which provide the selected attribute values.

The where-clause defines the restrictions to be applied in selecting the data values.

The values are perceived by the user as tuples, processed one tuple at a time. A status code is returned with the results of each request.

In LINUS the selection mechanism is mapping-oriented and the range-clause is replaced by the from-clause, and the order of the clauses is select . . . from . . . where . . .

The values are perceived by the user as a set of tuples (i.e., a relation). Error status codes are translated into messages and displayed to the user.

Examples of a Data Model (=Schema) Definition
(See C.J. Date, An Introduction to Database Systems, 2nd edition, p. 52):

domain:

```
integer fixed bin (17),
character char (20),
name char (32) -check_proc valid_name;
```

attributes:

```
city-name            character,
supplier_name        name,
part_name            character,
quantity             integer,
credit_status        integer,
weight_units         integer,
color_type           character,
supplier_number      integer;
```

relation:

```
company (supplier_number* supplier_name credit_status city)
item (part_number* part_name color_type weight_units city),
order (supplier_number* part_number* quantity);
```

3.1.1 Restriction

Restriction is done through use of the where-clause. The allowable relational operators in MRDS and LINUS are the following:

Symbol	Definition
=	equals
^=	not equals
<	less than
>	greater than
<=	less than or equals
>=	greater than or equals

Tuple attributes may be compared to string constants, arithmetic constants, tuple attributes within the same or different tuple variables, arithmetic expressions or scalar functions. Tuple attributes may also be compared to the values of program variables. Any domain may be compared with any other domain with conversion to a common data type performed according to Multics PL/I conversion rules.

These relational expressions can be combined into more general expressions through the use of the logical conjunction (&), logical inclusive (|) and logical negation (^) operators.

It is also possible to supply program variable values to the where-clause.

MRDS Example:

```
-range (i item) (o order)
-select i. part_number i. part_name
-where((o.part_number=i.part_number)&(o.supplier_number="Acme"))
```

LINUS Example:

```
select part_number part_name
from item
where part_number = {select part_number
                     from order where
                     supplier_number = "Acme"}
```

3.1.2 Quantification

Existential and universal quantification are implicitly supported through use of the intersection (inter), union (union) and difference (differ) set operators (see 3.1.3).

Absolute quantification is not supported.

3.1.3 Set Operations

The defined set operators are union (union), inter (intersection) and differ (difference).

The selected attributes must be union compatible.

MRDS Example:

```
(-range (c company)
-select c. city_name
-where c. supplier_name = "Blake")
-inter
(-range (i item)
-select i. city_name
-where i. part_name = "Bolt")
```

LINUS Example:

```
(select city_name
from company
where supplier_name = "Blake")
inter
(select city_name
from item
where part_name = "Bolt")
```

3.1.4 The only restriction on join operations is that the joining attributes be union compatible. A relation can be joined with another relation (see 3.1.1) or with itself.

MRDS Example:

```
-range (a item) (b item)
-select a. part_name
-where ((b. part_number = 503) & (a. city_name = b. city_name))
```

LINUS Example:

```
select part. part_name
from part: item five_o_three: item
where   five_o_three. part_number = 503 & five_o_three. city_name = part.
      city_name
```

3.1.5 Nesting and Closure

Qualifications can be nested. The qualifications can be used in retrieval and alteration operations. The qualification facilities are "relationally complete." The capabilities of existential and universal quantification are provided by the set operations (see 3.1.3).

3.1.6 Additional Aspects of Qualification

(Not Applicable)

3.2 RETRIEVAL AND PRESENTATION

3.2.1 Database Queries

3.2.1.1 MRDS

The manner in which the selection facility described in 3.1 is utilized in MRDS is as an argument in a CALL statement. This interface to MRDS can be used in any language containing a CALL interface that is supported by Multics (e.g., PL/I, Fortran, COBOL, etc.).

Tuples are returned a tuple-at-a-time. The first tuple is returned when the first CALL to the retrieve module is executed using a given selection expression. Subsequent tuples are retrieved by CALLing the retrieve module using the "-another" parameter in place of the original selection expression. A status code is returned when the set of tuples to be retrieved has been exhausted.

It is also possible to re-retrieve the last seen tuple by replacing the selection expression with "-current". This is useful for the modify operation (see 3.3.3).

MRDS allows for user-defined functions to be used within the where-clause. Absolute functions are not explicitly supported.

MRDS is considered to be relationally complete (see 3.1.5).

MRDS Examples using PL/I: (Get the names of all parts weighing twelve pounds)

```
(1)  o
     o
     o
     call  dsl_$retrieve (db_index,
           "-range (i item)
           -select i. part_name
           -where (i. weight_units = 12)",
           receiving_variable,
           status_code);
     o
     o
     o
     do while (status_code = 0);
     call  dsl_$retrieve (db_index,
           "-another", receiving_variable,
           status_code);
     o
     o
     o
     end;
(2)  dcl   weight_var fixed bin (35);
     o
     o
     o
     weight_var = 12;
     call  dsl_$retrieve (db_index,
           "-range (i item)
           -select i. part_name
           -where (i. weight_units = .V.)",
           weight_var, receiving_variable,
           status_code);
```

```
o
o
o
do while (status_code = 0);
call   dsl_$retrieve (db_index,
       "-another", receiving_variable,
       status_code);
o
o
o
end;
```

3.2.1.2 LINUS

In LINUS, the selection expression is executed interactively as part of a LINUS Language (LILA) text fragment. The complete set of selected rows (=tuples) are presented to the user when the print command is entered.

LINUS allows user-defined functions to be used in the where-clause and in the select-clause.

LINUS is considered to be relationally complete (see 3.1.5).

LINUS Example: (Get the names of all parts weighing twelve pounds).

First the user creates the desired selection expression on a text file using LILA, as follows (underscores indicate system generated prompt characters):

```
? lila
→10 select part_name
→20 from item
→30 where weight_units = 12
→ proc
→ quit
```

The user supplied information on lines numbered 10, 20 and 30 constitutes the selection expression and is called the LILA expression.

Satisfied that the above selection expression is correct, the user then enters:

```
? print
```

The user may also create a variable to be used in subsequent selection expressions.

For example, if the LILA expression is -

```
avg {select weight_units from item}
```

If the user then uses the set command as follows:

```
set   !avg_wu
```

Then the variable named !avg_wu contains the value denoting the average weight unit for all parts in the item relation.

This variable can then be used in another LILA expression as follows:

```
select part_name
from item
where weight_units = !avg_wu
```

The user may then retrieve all parts containing the average value, using the print command.

3.2.2 Retrieval of Information About Database Constituents

The data model (=schema) may be accessed by priviliged users. The operations available are listed in 2.2.2.

3.2.3 Retrieval of System Performance Data

Some monitoring data, such as the names of active concurrent users, is available to privileged users (see 2.2.2).

3.2.4 Report Generation

The LINUS print command provides a default format. It also allows the user to specify the character width of each printed column and to alter the maximum number of rows of data to be printed. If there are more than the maximum number of rows to be printed, the user is queried as to whether the remaining rows are to be printed. It also allows for a user-defined heading to be printed.

There also exists a create list command which directs retrieved data to a Multics word processing file, which may then be manipulated and formatted using standard word processing commands. (This capability is also available to MRDS.)

If more complex reporting of retrieved output is desired, the report command directs the retrieved output to the Multics Report Program Generator, which then processes the output according to a predefined report definition. (This capability is also available to MRDS.)

3.2.5 Constraints and Limitations

(Not Applicable)

3.2.6 Additional Aspects of Retrieval and Presentation

(Not Applicable)

3.3 ALTERATION

The delete and modify facilities operate in conjunction with a selection expression, just as does the retrieval facility. The insert facility does not utilize a selection expression.

3.3.1 Insert Facilities

The insert facility in MRDS and in LINUS is provided by the store operation. Tuples may be stored into one relation at a time. Values must be provided for every attribute defined in the base relation. If the user desires a non-key attribute value to be null, the null value must be explicitly provided. Uniqueness of tuples within a relation is enforced through the concatenated values constituting the primary key.

The first attempt to store a tuple into a relation must specify the relation name and the values to be stored in the same order and number as the associated attributes appear in the data model (=schema) or submodel (=view). In this case, the submodel (=view) must contain all the attributes contained in the model (=schema) for this base relation, although they may be renamed and reordered.

3.3.1.1 MRDS

After the first call to store a tuple in a relation has been executed, subsequent calls may specify "-another" in place of the relation name.

Example in PL/I:

```
call   dsl_$ store (db_index,
o                  "order",
o                  5553,
o                  3133,
                   200,
                   status_code);
do while (status_code = 0);
call   dsl_$ store (db_index,
o                  "-another",
o                  5662,
o                  2970,
                   350,
                   status_code);
end;
```

3.3.1.2 LINUS

LINUS allows tuples to be stored into a relation in several ways. The values to be stored may be specified in one of three ways: (1) directly within the command line, (2) intractively in response to prompting for each attribute, or (3) by placing a set of new values in a Multics file and providing the name of the file within the command line.

If (1) or (2) is used, the user has the option of visually verifying the values prior to their actual placement into the database. If (3) is used, the user can specify the delimiter character used to separate the values on the file to be stored from.

Examples (underscore indicates system generated output):

(1) ? store order 5553 3133 200 -brief

(2) ? store order 5665 4210 150
supplier number = 5665
part number = 4210
quantity = 150

OK? yes

(3) ? store order -brief
supplier number? 3030
part number? 2970
quantity? 59

3.3.2 Delete Facilities

The delete facility in MRDS and LINUS is provided by the delete operation. The delete operation is used in conjunction with the selection expression (see 3.1). The only constraints are that the select list must not reference more than one relation and must not contain any set operators (union, inter or differ). Other relations can be referenced in the where-clause. All selected tuples in the referenced base relation are deleted. Thus, if the base relation from which tuples are to be deleted is being referenced via a data submodel (=view), then all attributes defined in the base relation must also be defined in the data submodel (=view).

MRDS Example: (Delete all orders which refer to bolts).

```
call  dsl_$ delete (db_index,
      "-range (o order) (i item)
      -select o
      -where ((i. part_name = "Bolt") &
            (o. part_number = i. part_number)),"
            status_code);
```

LINUS Example: (Delete all orders which refer to bolts).

```
The LILA expression is -
      select *
      from order
      where part_number =   { select part_number
                              from item
                              where part_name = "Bolt" }
```

The LINUS command is -

delete

3.3.3 Modify Facilities

Relations can be altered by modify operations. The modify operation is used in conjunction with the selection expression (see 3.1). The select list must not reference more than one relation although other relations may be referenced in the where-clause. Primary keys cannot be modified. Any attempt to do so will result in an error status code. All attributes specified in the select list are modified for each tuple selected.

3.3.3.1 MRDS

Modification is performed on all selected tuples. It is possible to retrieve a tuple using the retrieve operation and then apply the modify operation using the "-current" parameter in place of the selection expression. This allows one-tuple-at-a-time modification.

MRDS Example: (Change to 500 the quantity of parts #9391 on order from supplier #444).

```
call  dsl_$ modify (db_index,
      "-range (o order)
      -select o. quantity
      -where ((o. suppler_number = 444) &
           o. part_number = 9391))", 500,
      status_code;
```

3.3.3.2 LINUS

Modification is performed on all selected rows of data. Data to be modified must be contained within one table, and key columns cannot be modified. New values may be specified within the request line, or they may be entered interactively, in response to LINUS prompting. In both cases, the user is asked to verify the new values before the modification takes place, unless the -brief control argument is specified. A processed LILA expression must be available before the modify command is entered, followed by the new values.

If the -brief argument is not provided, then LINUS displays a list of selected column names, together with the column_values as entered by the user, and requests that the user verify the correctness of the column_values before the modification operation proceeds. If the verification is negative, the modification does not take place. The user may reenter the modify request without again specifying the associated LILA expression.

New column_values may be specified in two forms: 1) as constants or as LINUS variables which have previously been set, or 2) as arithmetic expressions combining constants, LINUS variables, and possibly the name of the column being modified.

The select-clause of the associated LILA expression must specify columns from only one table, and only non-key columns may be selected. The select clause associated with a modify request must not contain arithmetic expressions, but is restricted to simple or qualified column names. Also, no set operators (union, inter, or differ) may appear in the LILA expression.

LINUS Examples:

(1) LILA expression:

```
select     quantity
from       order
where      supplier_number = 4455
```

To increase the quantity of all parts on order from the selected supplier by 10 percent, do:

```
? modify (quantity + .10 * quantity)
quantity = (quantity + .10 * quantity)
OK?  yes
```

(2) LILA expression:

```
select     weight_units
from       item
where      part_name = "Bolt"
```

To correct the designated weight unit of bolts, do:

```
? modify -brief
weight_units?  19
```

3.3.4 Commit and Undo Facilities

(Not Applicable)

3.3.5 Additional Alteration Facilities

(Not Applicable)

3.4 ADDITIONAL FUNCTIONAL CAPABILITIES

3.4.1 Arithmetic and String Operations

(See 2.6.2)

3.4.2 Sorting is not directly supported. (The base relations are implicitly ordered in ascending order on the primary key values, but this is a transient characteristic of the current implementation.) Selected data may be sorted within the Multics Report Program Generator. It may also be written to a file and sorted using the Multics sort command.

3.4.3 Library Functions

(See 2.6.2)

3.4.4 User-Defined Functions

User-defined functions can be created for use by MRDS or LINUS. They may be written in any language that accepts and processes a standard Multics argument list. The function name is made known to MRDS or LINUS by the declare operation. LINUS accommodates set (i.e., aggregate) functions and scalar functions. MRDS accommodates only the latter (See 2.6.2).

3.4.5 Transactions

MRDS and LINUS support concurrent access to a database. This is accomplished by opening a database using the open operation and specifying either the retrieval or update mode. (Shared usage is implied by these modes. If the user wishes non-shared access to the database the exclusive_retrieval or exclusive_update mode must be specified.)

If the database is opened in one of the shared modes, then it is incumbent upon the user to declare a scope of access prior to referencing the data. This is done by use of the set_scope and dl_scope (i.e., delete scope) operation. When setting a scope, the user specifies, for each relation, the action (retrieve, store, delete, modify or null) that is being requested as well as the action (retrieve, store, delete, modify, or null) which other users are to be prohibited from performing. This scope of access, once granted, cannot grow but it can shrink. That is, the user may delete part of the scope. The user is not allowed to declare another scope of access until all the current scope of access has been deleted. The user may also specify the maximum time to wait for a set_scope request to be honored.

MRDS Example:

```
call   dsl_$ set_scope (db_index, "item", 1, 2, 60, status_code);
o
o
o
o
call   dsl_$ dl_scope_all (db_index, status_code);
```

Note: In the set_scope operation the third argument indicates that the caller wishes to retrieve from the item relation. The fourth argument indicates the user wishes everyone else to be denied update privileges. The parameter 60 indicates the user wishes to wait no more than 60 seconds for the request to be granted.

LINUS Example:

To accomplish the same thing in LINUS, do as follows:

```
? set_scope item r sdm
```

Note: The default wait time is 30 seconds; sdm signifies store, delete and modify.

```
? del_scope *
```

3.4.6 Multi-Tuple Alterations

The modify and delete operations allow multiple tuples of one relation to be altered using some tuples of another relation as arguments to the operation (see 3.3.2 and 3.3.3).

3.4.7 Grouping

(Not Applicable)

3.4.8 Exception Handling Mechanisms

MRDS and LINUS rely on the exception handling mechanisms provided by the Multics operating system.

3.4.9 Additional Functional Capabilities

MRDS and LINUS support a snapshot view capability allowing users to define temporary relations (temporary tables in LINUS). The operation is called define_temp_rel (or define_temp_table). A temporary relation cannot be altered. It can be refined by creating another temporary relation. It can also be queried using the retrieve operation.

The define_temp_rel is executed in conjunction with a selection expression (see 3.1). The one variation is that in MRDS at least one of the attribute names specified in the select list must be followed by an asterisk (*) to denote it as a primary key component. Upon creation, it is assigned an index value which is returned to the user. This value is then used as an identifier of the temporary relation, for reference within subsequent operations.

MRDS Example:

```
call  dsl_$ define_temp_rel (db_index,
      "-range (i item)
      -select i. color_type i. part_name*
      -where (i. city_name = "London)",
      temp_rel_index,
      status_code);
```

In LINUS the primary key is specified in the define_temp_table command.

LINUS Example:

LILA expression:

```
select    color_type part_name
from      item
where     city_name = "London"
```

Then execute the command:

```
? define_temp_table  London_parts  part_name
```

4.0 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

The main components of an MRDS data base are:

(1) the data model (this corresponds roughly to the internal schema in the ANSI/SPARC model).

(2) the data submodel (this corresponds roughly to the external schema in the ANSI/SPARC model).

(3) the database itself.

The creation, generation and administration of the data model are considered data base administrator functions. The creation of the data submodel and its administration are viewed as functions performed by the user in conjunction with advice from the administrator.

4.1 DEFINITION FACILITIES

4.1.1 Constituents of a Database Definition

The MRDS (or LINUS) database definition consists of a definition of the:

- o domains
- o attributes
- o relations
- o indexes
- o data model
- o data submodel (optional)

The definitions of domains, attributes, relations and indexes (the secondary indexes which serve as quick-access paths to tuples) are placed on a text file.

(For an example, see 3.1.)

4.1.2 The create_mrds_db command creates an unpopulated data base and a data model (=schema) based on the definitions found in a text file (see 4.1.1). The database name is a parameter of this command.

The maximum number of relations in a database is 127.

4.1.3 Relation Definition

A relation is defined in the text file referenced by the create_mrds_db command. The relation definition consists of:

- o a relation name
- o the attribute names in a relation
- o an indicator as to which attribute names are primary key components.

The referenced attribute names must appear in a domain or attribute statement.

For Example (see 3.1.):

order (supplier_number* part_number* quantity)

4.1.4 View Definition

Data submodels are one type of view defined for MRDS.

Data submodel definition is accomplished with the create_mrds_dsm command. It allows the user to rename relations and attributes, omit relations and attributes and reorder attributes within a relation. (It does not allow for the redefinition of a data type, but this is allowed in the declaration of the receiving variable in the application program using MRDS.) The data submodel definition is placed in a text file, the name of which is a parameter of the create_mrds_dsm command. Submodel relations cannot span more than one base relation.

Example:

relation: co = company (city sno = supplier_number);

In this example, the company relation is renamed as the co relation. The co relation contains two attributes: the city (which is not renamed) and sno (which is the name given to supplier_number).

For defining the other type of view (i.e., temporary relation), see 3.4.9.

4.1.5 Tuple Definition

Tuples are implicitly defined as tuples of a relation (in MRDS) or rows of a table (in LINUS). There is no explicit tuple definition.

4.1.6 Attribute Definition

Attributes are defined in the text file referenced by create_mrds_db. They are defined by default with names identical to each domain name and may also be explicitly defined to range over a specified domain. In this case the attribute definition consists of the attribute followed by the associated domain name. For example, (see 3.1 and 4.1.3):

attribute: city_name   character

4.1.7 Domain Definition

Domains are defined in the text file referenced by create_mrds_db. Domain definitions consist of

- o the domain name
- o the data type (see 2.7.1)
- o an optional name of a data integrity checking procedure
- o an optional name of a data encoding procedure
- o an optional name of a data decoding procedure
- o an optional data type for the decoded value.

For example (see 3.1):

```
domain: name char (32)
      -check_proc valid_name_routine
      -encode_proc encode_routine
      -decode_proc decode_routine
      -decode_dcl float bin (72)
```

4.1.8 Definition of Additional Database Consituents

Secondary indexes may be defined for any attribute in any relation. The index is defined in an index statement contained in the text file referenced by create_mrds_db. Each secondary index must consist of no more than one attribute.

For example (see 3.1):

```
index: company (city supplier_name)
```

4.2 GENERATION FACILITIES

4.2.1 Constituents of a Database Generation

The create_mrds_db command creates an unpopulated database with the components defined in the referenced text file. If the text file containing the definition discussed in 4.1 is named sample_db.cmdb, the command to create a database named new_db would appear as follows:

```
create_mrds_db  sample_db.cmdb  new_db
```

This would create a Multics directory named new_db. Immediately subordinate to this directory are a number of files.

- o The database control file (dbc) contains information necessary to control concurrent access to the database.
- o The database model file (db_model) contains data model information common to the entire database, such as descriptions of all the domains and a list of all relation names.
- o For each relation, there is created a file model. The file model contains data model information unique to each file, such as the relation defintion and the attribute definitions.
- o For each relation there is created a null (or empty) file which may be populated using the store function (see 3.3.1).

The create_mrds_dsm command creates a data submodel which resides separate from the database. It contains database location information and alias information.

4.2.2 Generation of Database Constituents

The database files (i.e., relations) are populated using the store function (see 3.3.1).

4.3 DATABASE REDEFINITION

4.3.1 Renaming Database Constituents

Database relation names and attribute names can be renamed by creating a temporary database using the new definition and then using standard Multics facilities to replace the original file model and affected file name with the new file model and file name in the database. The domain names can be renamed by replacing the original db_model file with the new db_model file using standard Multics facilities.

Data submodels must be modified to reflect such renaming, but application programs using the data submodels remain unaffected.

4.3.2 Redefining Database Constituents

Constraints on domains can be added, removed or changed.

4.4 DATABASE REGENERATION AND REORGANIZATION

4.4.1 System-Controlled

(Not Applicable)

4.4.2 DBA-Controlled

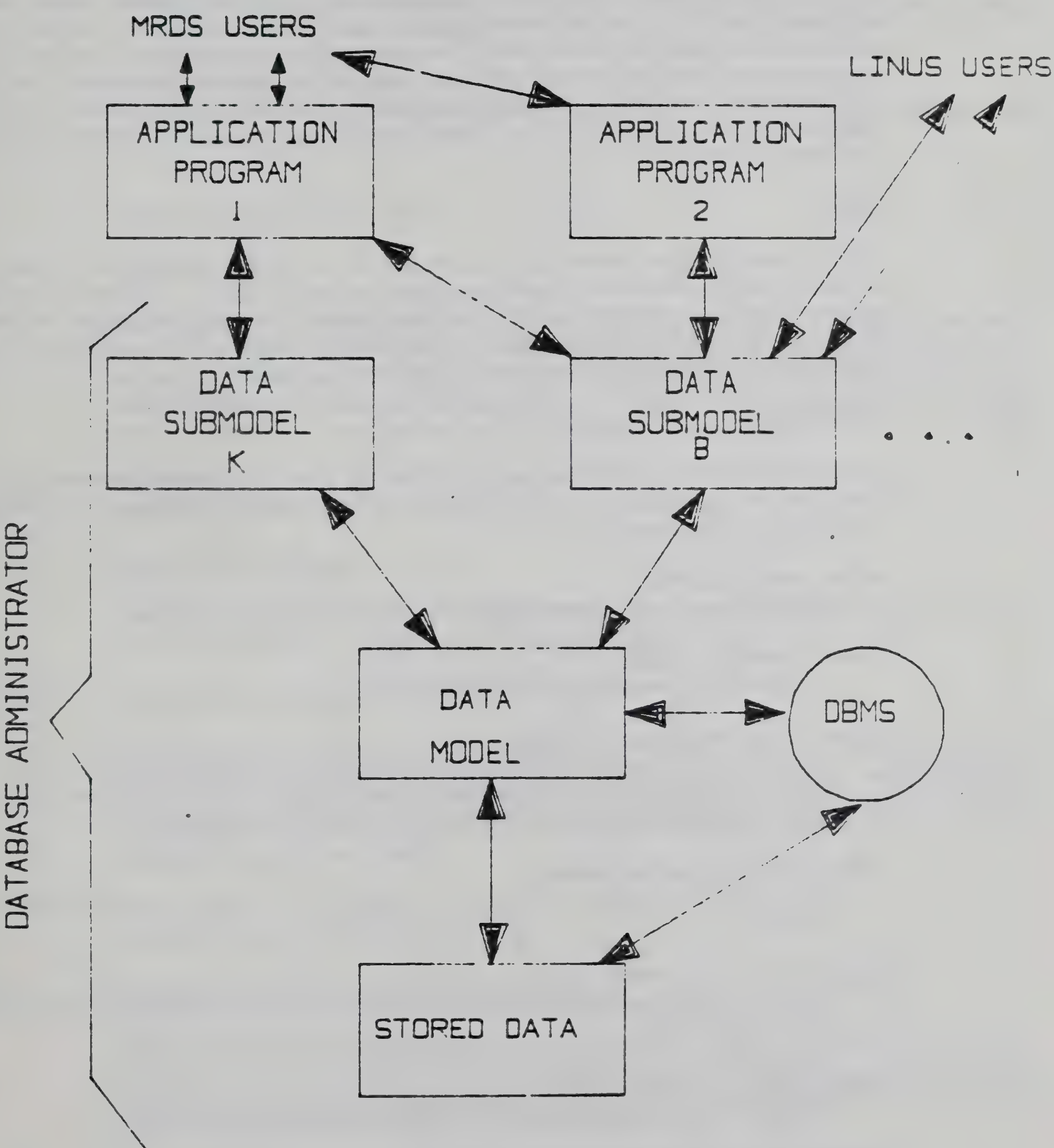
(Not Applicable)

4.5 DATABASE DICTIONARY

The database dictionary information is maintained in the db_model file and in the file model files.

5.0 INTERFACES AND DBMS ARCHITECTURE

5.1 System Architecture



MRDS USERS
LINUS USERS
APPLICATION PROGRAM 1
APPLICATION PROGRAM 2
DATA SUBMODEL K
DATA SUBMODEL B
DATA MODEL
DBMS
STORED DATA
DATABASE ADMINISTRATOR

5.2 Interface Descriptions

5.2.1 MRDS Data Sublanguage

The MRDS data sublanguage provides a CALL-level interface for application programs to access an MRDS database. This language can be used in any language supported by Multics which supports the CALL statement. Specifically it can be used in COBOL, PL/I, FORTRAN and APL. Data is transmitted to the program in piped mode, a tuple-at-a-time, from the set of data specified by the user's selection expression (see 3.2.1). All status information is transmitted via a status return code in each CALL statement. Security is provided by Multics access control lists applied at the database and file (i.e., relation level), see 6.1. Attribute level security is provided by access control lists applied to the data submodel. Recovery is provided by the normal Multics operating system features. For more details, see the MRDS descriptions in Sections 2, 3, and 4.

5.2.2 LINUS

LINUS provides an interactive interface to a MRDS database. Data is transmitted as a table of rows and columns (see 3.2.1.2). Abnormal status information is presented to the user as English language messages on the terminal. For security and recovery features, see 5.2.1. For more details see the appropriate LINUS descriptions in sections 2, 3 and 4.

5.2.3 Administrative Interfaces

The administrative interfaces are provided by a set of interactive commands. They include the following commands (each command is followed by a short version of the command):

adjust_mrds_db, amdb
: reinitializes a data base concurrent access control file (dbc).

create_mrds_db, cmdb
: creates an unpopulated MRDS database.

create_mrds_dm_include, cmdmi
: builds a PL/I include file of structure declarations where the level 1 names are those of the model/submodel relations, and where the level 2 declarations match those of the attributes in each relation.

create_mrds_dm_table, cmdmt
: provides a picture, or graphic display of the data model/submodel structure.

create_mrds_dsm, cmdsm
: creates a data submodel definition file (provides an alternate description of the data base).

display_mrds_db_status, dmdbs
: displays the open and concurrent access users of a data base.

display_mrds_db_version, dmdv
: displays the version of an MRDS data model/submodel.

display_mrds_dm, dmdm
: displays specified information from the data model.

display_mrds_dsm, dmdsm
: displays specified information from the data submodel and optionally displays related data model information.

display_mrds_open_dbs, dmod
: displays a list of pathnames and opening indexes of all currently opened data bases in the user's process.

quiesce_mrds_db, qmdb
: places the data base in a quiescent (non-active) state for such purposes as dumping, etc.

6.0 OPERATIONAL ASPECTS

6.1 SECURITY

Security will be provided through the Data Submodel mechanism in the next product release. It will be possible to specify null, read and update permission at the attribute level for users of a given submodel. It will also be possible to restrict users from appending and deleting tuples at the relation level and to restrict users from examining the attributes of a relation.

6.2 PHYSICAL INTEGRITY

6.2.1 Concurrency Control

Deadlocks are prevented and concurrency control is provided through use of the "set scope" and "delete scope" functions (see 3.4.5).

6.2.2 Recovery and Restart

The quiesce_mrds_db command allows the administrator to force a database into a quiescent state. The database can then be saved using normal Multics facilities. If it is necessary to restore a database after a crash, this saved copy can be restored using normal Multics facilities in conjunction with the quiesce_mrds_db command.

6.3 OPERATING ENVIRONMENT

6.3.1 Software Environment (Operating System)

MRDS and LINUS utilize Multics system features to a great degree. The data is stored on the database using the Multics space manager. Databases are stored in the Multics storage system hierarchy. Report generation is provided by the Multics Report Program Generator (MRPG).

6.3.2 Hardware Environment (CPU, Memory, Peripherals)

Not applicable, since MRDS and LINUS run in a virtual memory dynamic paging environment.

7.0 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS

MRDS and LINUS are simpler and easier to use than other non-relational database management systems. The power of the data selection language allows users to retrieve what is wanted with one command without having to worry about coding complex procedures to retrieve the desired data.

MRDS and LINUS provide a significant degree of data independence by removing access path information from the user interface. Additional data independence is achieved through use of the data submodel which allows users to reference data using aliases and user specific views. Through use of the data submodel views, databases can be restructured without impacting MRDS application programs or LINUS queries.

MRDS and LINUS optimize each query according to storage considerations (such as secondary indexes) and progress is being made in optimizing on dynamic characteristics (such as the number of tuples in a relation).

The non-procedural aspect of MRDS allows application programmers to ignore many representational details, such as storage structures.

The high level interface provided by MRDS and LINUS is ideal for adaptation to a database machine facility and contributes toward the eventual distribution of databases.

8.0 DATABASE APPLICATIONS USING THE SYSTEM

1. Library Catalog Application
2. Statistical Analysis
3. Seismic Data Collection
4. Patent Querying Application
5. End User Facility Development
6. Data Base Concepts Teaching Application
7. Auto Tracking Application

MRS
System Evaluation

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October 1980

1 INTRODUCTION

.1 Identification

RS is a relational database management system for mini and micro computer pplications. It was designed and implemented by the Database Project of the omputer Systems Research Group, University of Toronto, under the direction of rof. D. Tsichritzis.

.2 Status

.2.1 System

ꞫS was released in July 1979. It is available from the Computer Systems esearch Group, University of Toronto, for a distribution fee. The current ersion has been distributed to over 50 installations worldwide. (See 8.1.)

2.2 Applications

ꞫS is a general-purpose Database Management System suitable for applications ıvolving small databases (to approximately 1 megabyte). It is not suitable ır statistical databases due to limited built-in arithmetic capabilities.

ıere are two main restrictions: 1) it can support no more than 30,000 tuples ·r relation; and 2) it can support a maximum of 70 attributes per relation.

ample:

e following is an example of a simple application from the MRS User's nual, which will be used throughout this analysis tc illustrate features of

MRS. It consists of a database storing information on movies, directors, and actors -- a small film library. This database consists of two relations: **movies** and **actors**. **Movies** stores the name of the movie, the year it was made, and the name of its director. **Actors** also stores the movie's name, as well the names of as its stars. Any one movie would have only one entry in **movies**, but might have several in **actors** if it had more than one star. Sample entries for **movies** and **actors** are shown below.

********** movies **********

movie_name (char)	year_made (numeric)	director (char)
Coming Home	1979	Hal Ashby
Heaven Can Wait	1978	Warren Beatty
Superman	1979	Richard Donner
Love and Death	1976	Woody Allen

********** actors **********

actor_name (char)	film (char)
Jane Fonda	Coming Home
John Voight	Coming Home
Warren Beatty	Heaven Can Wait
Julie Christie	Heaven Can Wait
Woody Allen	Love and Death

.3 System Background

MRS is a member of the SQL database management family. It is written in he "C" programming language and is implemented on the LSI-11/PDP-11 family of omputers under the Mini-UNIX/UNIX operating systems. MRS was originally esigned as a workstation in a distributed database management system by I. add, J. Kornatowski, and R. Hudyma. This prototype was subsequently edesigned and implemented by J. Kornatowski and I. Ladd to become a practical tandalone database management system. This is the version presently distri-uted by the Computer Systems Research Group. Due to the widespread accep-ance of MRS and ongoing user demands, the redesigners have produced a new, pported and enhanced commercial product called MISTRESS that is downward-mpatible with MRS at the query language level.

4 Overall Philosophy

The philosophy of MRS is a small system that is simple in its design, exible in its abilities, usable by the ordinary person, and runnable on a de family of mini and microcomputers. MRS is integrated with the operating stem under which it runs. It complements and interacts with the operating stem utilities. It does not duplicate the function of the system utilities. S fulfils the need for a practical small Database Management System, and ny of its features and developments are a direct consequence of user feed-ck. It provides a suitable working environment for the rapid development of otoype applications.

1.5 Essentialy Relational Characteristics

MRS is a relational Database Management System modelled on "System R". The Query language based on SQL implements many of the most common commands and adds a number of practical features demanded by users.

1.6 Interfaces

The query language/operating system interface in MRS allows for the following capabilities:

* Database Schema Definition
* Query Language
* Database Altering
* Database Generation
* Data Entry
* Database load and dump
* Definition of indices

The Interactive Subsystem interface in MRS allows for the following:

* interactive insertions
* interactive updates
* interactive deletions

.7 Documentation

. Kornatowski (1979). The MRS User's Manual, University of Toronto Press.

. Ladd (1979). A Distributed Database Management System Based on Microcomputers, MSc Thesis, University of Toronto.

. Hudyma, I. Ladd, and J. Kornatowski (1979). Implementing a microcomputer database management system. Computer Systems Research Group Technical Report, University of Toronto.

. Hudyma (1978). Architecture of Microcomputer Distributed Database Systems. M.Sc. Thesis, University of Toronto.

.8 General System Description

RS is a useful tool for relational applications. It is a small, powerful, ntegrated tool for real databases.

2 DATABASE CONSTITUENTS

2.1 General Description

System Term	Feature Catalogue Term
database	database
relation (table)	relation
tuple	tuple
attribute	attribute
attribute name	attribute name
attribute type	attribute type

2.2 Database

2.2.1 Database Structure

A database is described by the name of the operating system directory in which it resides. It consists of the data directory, the relations and their associated indices.

2.2.2 Database Operations

The following operations are available for dealing with a database: create a database directory; list the names of all relations in a database; perform backup and recovery via single commands; and change the security (access) to the database.

These are performed by "mkmrsdb", "display", "backup", "restore", and "protect", respectively.

Examples:

```
mkmrsdb DATA       (create an MRS database directory called DATA)
display table;     (list all relations in the database directory)
backup DATA        (perform backup)
restore DATA       (perform restore)
protect DATA       (make the database totally private)
```

2.2.3 Database Constraints

Constraints are not supported.

2.2.4 Additional Database Properties

2.3 Relation

2.3.1 Relation Structure

A relation is identified by a (unique) entry in the data directory of the database. Alias names are not allowed. A relation is a collection (table) of tuples; duplicate tuples are allowed. The order of attributes is used only on database queries which do not specify an alternate order.

2.3.2 Relation Operations

The following operations are available for dealing with relations: defining and creating a relation; deleting a relation; displaying the attributes of a relation; qualified or unqualified selection from a relation; performing joins; and performing "bulk" insertion, updates, and deletion.

Examples:

```
create table movies
                (movie_name char(30),year_made numeric,director char(
create table actors
                (film char(30), actor_name char(20));
drop table movies;
display table movies;
select from movies;
select from movies where year_made > 1978;
select director,year_made from movies,actors
                where movie_name=film  and actor_name=director;
insert intomovies from 'moviefile';
update movies set year_made=1979;
delete from movies where movie_name='Superman';
```

.3.3 Relation Constraints

.3.4 Additional Properties of Relations

4 Views

ews are not supported.

4.1 View Structure

4.2 View Operations

4.3 View Constraints

4.4 Additional Properties of Views

5 Tuple

2.5.1 Tuple Structure

A tuple is a collection of attribute values.

2.5.2 Tuple Operations

The following operations are available for dealing with tuples: inserting; updating; and deleting. Implicit operations are available for existence testing and equality testing.

Examples:

```
insert into movies: ['Coming Home',1978,'Warren Batty'];
update movies set director='Warren Beatty';
delete from movies where year_made <= 1970;
```

2.5.3 Tuple Constraints

2.5.4 Additional Properties of Tuples

There is an exclusive tuple-oriented interface, the interactive subsystem. Tuples are addressed implicitly.

Examples:

MRS prompts are in boldface; entries by the user are in roman type.

```
insert into movies;
movie_name: Coming Home
year_made: 1979
director:       Hal Ashby
>>>READY  .e

movie_name: Heaven Can Wait
year_made: 1987
director: .↑
year_made: 1987 1978
director:  Warren Beatty
```

```
>>>READY  .d
movie_name: Heaven Can Wait
year_made: 1978
director: Warren Beatty
>>>READY  .e

movie_name: New York
year_made: 1980
director:       Woody Allen
>>>READY  .>movie_name
movie_name: New York Manhattan
>>>READY   .e

movie_name: .q

Number of tuples entered = 3
*update movies set movie_name,year_made
                where movie_name = 'Manhattan';

movie_name: Manhattan
year_made: 1980 1979
>>>READY   .e
Number of tuples updated = 1
*
```

.6 Attribute

.6.1 Attribute Structure

ı attribute is a component of a relation identified by a (unique) name and ɔmain. An attribute value is a component of a tuple with a value of the ɔrresponding domain. Alias names cannot be defined. The attribute names are ıserted into the data directory at the time the relation is defined and ·eated.

2.6.2 Attribute Operations

The following attribute operations are available:

```
< <= = >= > ¬=

MATCH (full pattern matching)

Inclusion in sets of values derived from other relations

COUNT, MAX, MIN, UNIQUE
```

There are no coersion rules. Attribute operations are only allowed on attributes of the same domain.

Examples:

```
select from movies
              where year_made>= 1975;
select max year_made from movies;
select count frommovies;
select min year_made from movies,actors
              where movie_name=film and
              actor_name='Jane Fonda';
select unique film from actors;
```

2.6.3 Attribute Constraints

.6.4 Additional Properties of Attributes

.7 Domain

.7.1 Domain Structure

vo domains are supported: the NUMERIC domain of integers; and the CHAR domain F variable-length character strings. A NULL value is a special value in each F these domains.

kamples:

```
'eate table movies
               (movie_name char(30), director char(20), year_made numeric));
```

7.2 Domain Operations

7.3 Domain Constraints

7.4 Additional Properties of Domains

2.8 Additional Database Constituents

An additional database consitituent is the index, a mechanism for improving the performance of some database operations. An index on an attribute may be created or deleted by the user with a single command, but its physical structure, maintenance, and use by the database management system is entirely transparent to him.

Examples:

```
create index years on movies (year_made);
create index films on actors(films);
```

3 FUNCTIONAL CAPABILITIES

3.1 Qualification

'he qualification is an English-like predicate calculus expression with predi-:ate joined by AND and OR connectives. The expression is applied to each uple in the specified relations.

xamples:

```
where year_made=1978 or year_made=1980;
where year_made=1979 and director='Hal Ashby';
```

.1.1 Restriction

estrictions are expressed by predicates which are comparisons of attributes ɔ constants or attributes to attributes. The standard six conditionals are sed (< <= = >= > ¬=), as well as ¢match' which is a general pattern matching ɔnditional. Only values of the same type may be compared.

xamples:

```
select from movies
              where year_made=1978 or year_made=1980;
select from movies
              where year_made=1979 and director='Hal Ashby';
```

3.1.2 Quantification

Quantification is implicit in that the qualification is applied to each tuple in the specified relations.

3.1.3 Set Operations

3.1.4 Joining

Two relations can be joined at the same time, but a relation is not allowed to be joined to itself. Joining attributes need not have special properties. Joining is implicit with the qualification operating on more than one relation. The truth-valued expression in this case is applied to each tuple in the Cartesian product of the relations. The general Cartesian product is restricted to the required join by including a predicate in the expression relating attributes from each of the two relations. This mechanism allows a general join including equi joins and natural joins.

Examples:

```
select actor_name from movies,actors
                where movie_name=film and year_made > 1975;
select year_made,actor_name from movies,actors
                where movie_name=film
                and actor_name match 'Warren Beatty';

select from movies,actors where
                movie_name = film and actor_name = 'Jane Fonda';
```

.1.5 Nesting and Closure

third type of predicate is used for nesting. This compares an attribute to set of values of the same type obtained by a projection on the qualified uples of a relation. The comparison is whether the attribute value is in the otained set or not.

xamples:

```
where movie_name in select movie_name  from  movies
               where director match 'Hal Ashby';
```

.1.6 Additional Aspects of Qualification

.2 Retrieval and Presentation

2.1 Database Queries

ueries are expressed by SELECT statements. They allow projection and functonal operations on qualified tuples.

amples:

```
select from movies;
```

produces output of the form:

```
movie_name                 year_made   director

Coming Home                1978        Hal Ashby
Superman                   1979        Richard Donner
Heaven Can Wait            1978        Warren Beatty
```

```
select year_made from movies;
```

produces output of the form:

```
year_made
```

```
1978
1980
1979
1980
1979
1975
1978
1977
1980
```

select unique year_made from movies;

produces output of the form:

```
year_made

1977
1978
1980
```

3.2.2 Retrieval of Information About Database Constituents

The DISPLAY TABLE command allows the user to find out the names of all relations in the database. It also allows him to find out attribute names, tuples, and other relevant information for a named relation. In general, this command interacts with the other facilities through the mechanism of operating system commands and files.

Examples:

display table;

produces the output:

```
******* TABLES *******

        movies
        actors
```

display table movies;

produces the output:

```
******** movies ********        LENGTH =  16    FIELDS = 3

movie_name     CHAR (30)
```

```
year_made      NUMERIC
director       CHAR (20)
```

:.2.3 Retrieval of System Performance Data

.2.4 Report Generation

.2.5 Constraints and Limitations

.2.6 Additional Aspects of Retrieval and Presentation

.3 Alteration

.3.1 Insert Facilities

he insertion operation adds a tuple to a relation. All unspecified attribute alues are set to NULL. A given attribute value must match the specified type or that attribute. There are two modes of insertion. The English-like nsert allows the direct insertion of a tuple without prompting. The interac-ive insert allows for the successive insertion of multiple tuples. It rompts for each attribute value with the name of the corresponding attribute, nd requests the user to confirm the insertion. It incorporates many useful eatures, such as the ability to back up to the last attribute value entered nd alter it, display the attribute values before entering, change any named ttribute value, and re-promt on errors.

kamples:

English-like insertion:

insert into movies:

```
                    ['Coming Home',1978,'Hal Ashby'];
insert into movies (year_made,actor_name)
                    [1978,'Jane Fonda'];
```

Interactive (the prompt is italic):

```
*insert into movies;
movie name: 'Coming Home'
year made: 1978
director: 'Hal Ashby'
>>>READY: .e

movie name: 'Heaven Can Wait'
year made: 1987
director: 'Warren Beatty'
>>>READY: .>year_made
year made: 1987 1978
>>>>READY:  .d
movie name: Heaven can Wait
year made: 1978
director: Warren Beatty
>>>>READY   .e
```

3.3.2 Delete Facilities

The deletion operation deletes qualified tuples from a relation. There are two modes of deletion. The English-like delete allows the direct deletion of a set of qualified tuples without prompting. The interactive delete (update) presents each attribute value of each qualified tuple with the name of the corresponding attribute and requests the user to confirm the deletion.

Examples:

English-like delete:

```
delete from movies where
                director match 'Warren Beatty';
```

Interactive:

```
update796movieswhere director match 'Warren Beatty';
movie name: Heaven Can Wait
year made: 1978
director: Warren Beatty
>>>>READY   .x
```

```
Number of tuples deleted = 1
```

.3.3 Modify Facilities

ıe update operation updates qualified tuples of a relation. There are two ɔdes of update. The English-like update allows the direct update of a set of ɹalified tuples by storing, without prompting, the specified attribute values ıto the corresponding attributes. The interactive update prompts for each ttribute value of each qualified tuple with the name of the corresponding ttribute, as well as the original value, and requests the user to confirm the ɔdate.

xamples:

```
English-like update:

update movies set year_made = 1978
                  where actor_name match 'Warren Beatty';

Interactive:

update movies;
movie name: Heaven Can Wait
year made: 1987  1978
director: Warren Beatty
>>> READY: .d
movie name: Heaven Can Wait
year made: 1978
director: Warren Beatty
>>> READY: .e

Number of tuples updated = 1
```

3.3.4 Commit and Undo Facilities

3.3.5 Additional Alteration Facilities

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

3.4.2 Sorting

A general-purpose sort capability is available using the MRS/operating system interface. The order will be preserved until the next alteration operation.

Examples:

```
into 'movie_list' select director,year_made from movies;
do 'sort movie_list';
```

3.4.3 Library Functions

The following functions are supported:

MAX selects the largest value of the specified attribute

MIN selects the smallest value of the specified attribute

COUNT shows how many tuples satisfied the selection

UNIQUE sorts tuples and removes duplicates

:xamples:

```
select max year_made from  movies;
```

produces the output:

Maximum value = 1980

```
select min year_made from movies;
```

produces the output:

Minium value = 1971

```
select count from movies;
```

produces the output:

Number of tuples retreived = 8

```
select unique year_made from movies;
```

produces the output:

year_made

```
1971
1975
1978
1979
1980
```

3.4.4 <u>User-Defined Functions</u>

3.4.5 <u>Transactions</u>

3.4.6 <u>Multi-Tuple Alterations</u>

3.4.7 <u>Grouping</u>

3.4.8 <u>Exception Handling Mechanisms</u>

If a command is in error, MRS rejects it and preserves the state of the database. User-defined triggers are not supported.

3.4.9 <u>Additional Functional Capabilities</u>

4 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

.1 Definition Facilities

here are no separate facilities for the definition and generation of database onstituents. Defining a shema automatically results in creation, and creaion automatically results in definition.

.1.1 Constituents of a Database Definition

database definition consists of a series of commands defining the relations ı a database and the indices for these relations. Each relation definition efines the attributes and domains. The database definition is stored in the atabase directory.

.1.2 Database Definition

xamples:

```
create table movies
        (movie_name char(30),
         year_made numeric,
         director char(20));

create table actors
        (film char(30),
         actor_name char(20));

create index years on movies(year_made);
create index actors on actors(actor_name);
```

ıere are no inherent limits to the number of relations.

4.1.3 Relation Definition

A relation is defined by the "create table" command.

Examples:

```
create table movies
        (movie_name char(30),
         year_made numeric),
         director char(20));
```

There are no inherent limits to the number of attributes and the order of definition. Keys are not supported.

4.1.4 View Definition

4.1.5 Tuple Definition

A tuple is defined by its relation. See 4.1.3.

4.1.6 Attribute Definition

An attribute is defined at relation definition time when it is given a name and a domain. See 4.1.3.

.1.7 Domain Definition

here are two domain types:

CHAR(n)

and

NUMERIC

ee section 4.1.3.

.1.8 Definition of Additional Database Constituents

.2 Generation Facilities

.2.1 Constituents of a Database Generation

11 constituents of a database may be created, destroyed, added, or deleted ynamically. A database is generated when the relations comprising it are efined. The database directory, which is initialized by a separate process, s automatically updated.

4.2.2 Generation of Database Constituents

The database directory is generated with the "mkmrsdb" command. Relations, attributes, and domains are generated with the "create table" command. Indices are generated with the "create index" command. Tuples may be loaded with a bulk insertion command.

Examples:

```
mkmrsdb DATA                   creates database directory called "DATA"
create table movies(...)       creates relation,attributes, domains
create index years
   on movies(year_made)        creates index on relation "movies"
insert into movies
  from 'movie_list'            bulk insertion of tuples from prepared list
```

4.3 Database Redefinition

All constituents of a database can be dynamically re-defined by deleting the old definition and creating a new one. Tuples may be dumped into a file and reloaded.

4.3.1 Renaming Database Constituents

.3.2 Redefining Database Constituents

.4 Database Regeneration and Reorganization

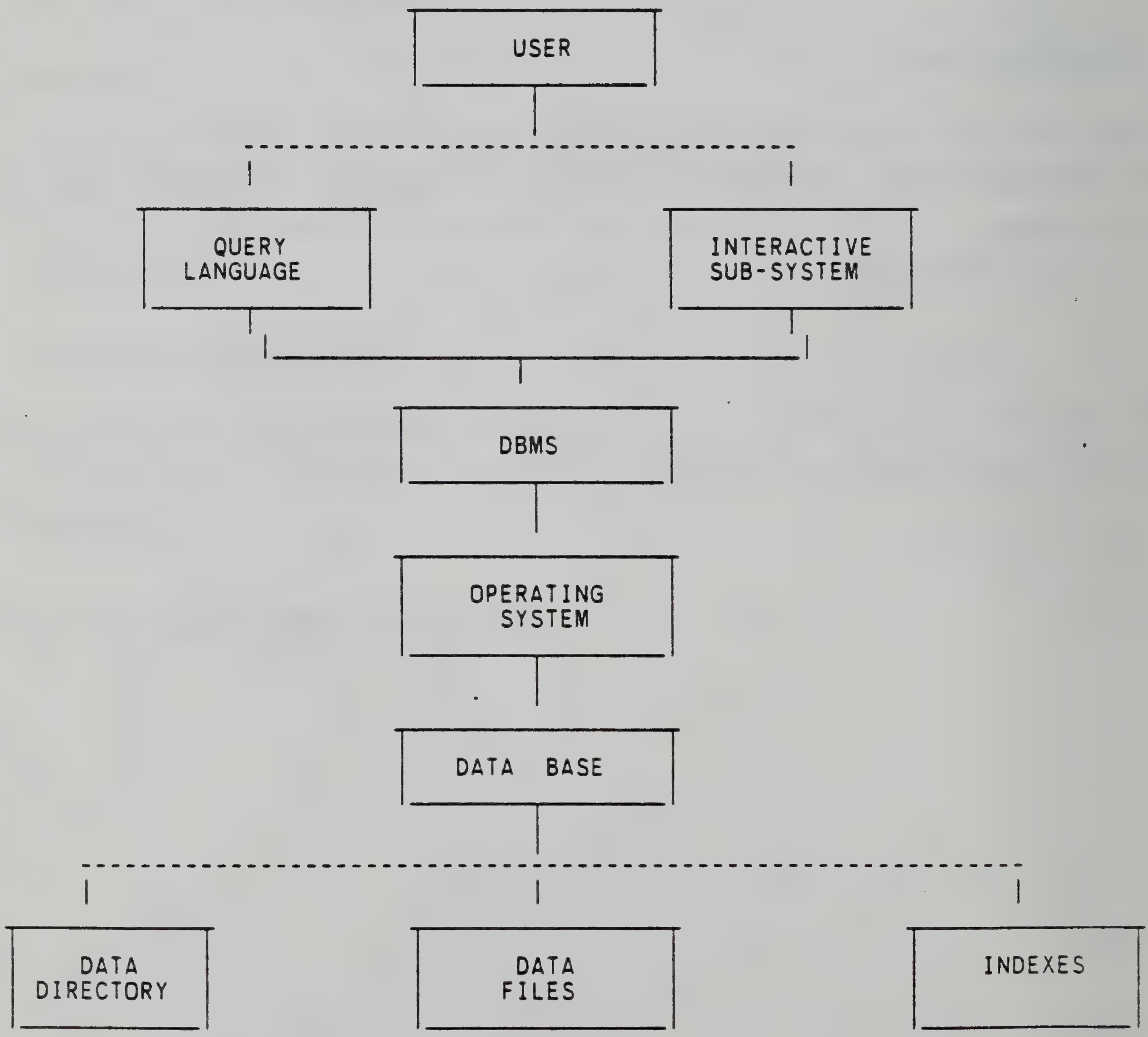
ee section 4.3.

.5 Data Dictionary

data dictionary (data directory) is maintained for each database. It stores he database schema, relations, attributes, and domains. It supports queries n the schema.

5 INTERFACES AND DATABASE MANAGEMENT SYSTEM ARCHITECTURE

5.1 System Architecture



5.2 Interface Descriptions

1. Query Language / Data Base

2 Interactive Subsystem / Data Base

.2.1 Query Language

he query language is based on SQL and designed for use by users of minimal xperience. The user perception of the database is a set of tables.

.2.2 Interactive Subsystem

he Interactive subsystem is based on user tastes and designed for use by sers with no experience. The user perception of the database is one tuple of relation at a time. The subsystem allows manipulation of attribute values ithin a tuple.

6 OPERATIONAL ASPECTS

6.1 Security

6.1.1 Access Control

MRS uses the capabilities of the file protection/access scheme provided by the operating system. In general, relations are readable but non-modifiable by others. A user may change any database or relation belonging to him to be modifiable (full access), or non-readable (full security) by others, or any combination.

6.1.2 Capabilities

6.2 Physical Security

6.2.1 Concurrency Control

.2.2 Crash Recovery

ıe database may be backed up and restored at the user's command.

.3 Operating Environment

3.1 Software Environment (Operating System)

ʔS has been designed as an integrated tool within the operating system ıvironment. It makes use of the operating system, its utilities, and other ·ograms to enhance its capabilities.

:S is written in the "C" language with the Query Language parser written in ACC". It is portable within Mini-UNIX and UNIX environments.

3.2 Hardware Environment (CPU, Memory, Peripherals)

MRS is portable within the Mini-UNIX and UNIX family, it has been run on ny combinations of PDP-11 processors and disks.

U: LSI-11, LSI-11/23, PDP-11/05, PDP-11/10, PDP-11/34, PDP-11/40, PDP-11/44, PDP-11/45, PDP-11/50, PDP-11/70, etc.

sk: From double-density, dual drive floppy disks up to large hard disks.

7 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERAL DATABASE MANAGEMENT SYSTEM PROBLE

7.1 Advantages

Since it is based on sets, the query language is easily understood by non-database people. We have trained many such in a remarkably short period of time. The query language is reasonably clear in its concepts and may be used as the basis of many forms of interaction with the database.

The query language allows commands to be packaged and executed as a unit, thus creating a custom high-level user-oriented command based system. The natural "table-like" format can be easily integrated with other programs to build prototypes and applications with speed and flexibility.

7.2 Disadvantages

A single table has been found to be a natural concept for many "non-computer" users. However, the concept of a join and the various join operations are a much more difficult set of concepts. Users in general prefer to deal with only one table rather than using joins. Thus, applications have been packaged to look like a single table, even if the underlying structure consists of several tables and joins.

8 DATABASE APPLICATIONS USING THE SYSTEM

IRS has been distributed internationally to over 50 Universities, Colleges, ınd commercial organizations (see 8.1). its extensive distribution,abases, it ıas become impossible to keep track of all applications. However, some typi- :al uses at the University of Toronto include:

ATHENIANS: Historical/Social database of noted ancient Athenians

CRABS: Computerized Reprint and Bibliographic System

DISTRIB: Records of software distributions

MES: Mark Entry System -- extensive system for keeping track of student marks

RS has been closely involved in other research projects at the Computer Sysems Research Group, and has become an integral part of such packages as OFS Office Form System), for form manipulations, and TLA, an office procedure pecification and information package with a form system interface. OFS and LA are also distributed by C.S.R.G.

Feature Analysis of Relational Concepts, Languages and Systems for NOMAD and NOMAD2*

by
Daniel R. Ries

Computer Corporation of America
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Cambridge, Massachusetts 02139

October 1980

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*Prepared while the author was at Lawrence Livermore Laboratory.

Feature Analysis of Relational Concepts, Languages and Systems for NOMAD™ and NOMAD2™

Prepared by:

Daniel R. Ries
October, 1980

FORWARD

This report was prepared for inclusion in a Feature Catalogue of Relational Concepts, Languages and Systems being prepared by the Relational Database Task Group of ANSI/X3/SPARC - Database Systems Study Group. The format and content of the report are based on the Working Paper RTG-80-81 of the relational database task group. This report compares NOMAD/NOMAD2 to the terms and definitions of that paper and not to other commercial products.

1.0 INTRODUCTION

1.1 Name of System: NOMAD, Release 6

Available From: National CSS, Inc.
187 Danbury Road
Wilton, Connecticut 06897

1.2 <u>Status</u>

1.2.1 System

Current System: NOMAD, Release 6 has been available since May 1978.

NOMAD2 is available in July, 1980.

1.2.2 Applications

NOMAD is suitable for and used in an extremely wide variety of applications. There are no inherent limitations on the total size of the applications except the machine limitations on the System NOMAD is running on.

1.3 <u>Database System Background</u>

The NOMAD database management system was initially released in 1974. The system is independent of any particular class of systems and is not based on any other particular system.

1.4 <u>Overall Philosophy</u>

NOMAD was developed to provide users of National CSS, Inc.'s timesharing services with a database management system. The creators of the system saw a strong need for a report writer which could produce reports from different records. Both hierarchial and normalized records could be combined using relational joining type operators. Furthermore, the developers of the system saw the need

to allow the output of such reports to be stored in a format suitable for further reports in the database.

1.5 Essentially Relational Characteristics

NOMAD can be used as a fully relational system. It supports a data sublanguage which can perform the functions of the relational algebra without using iteration or recursion. NOMAD supports several different join operators. Note that in the data sublanguage, a sequence of high level, set oriented commands may have to be used to achieve the power of the relational algebra. In particular, the 'join' commands cannot be arbitrarily nested. Instead these commands can be used to create other relations which can then be used in subsequent commands. The details on the nesting are described in Section 2.1.5.

NOMAD does support other features which allow the user to define some database constituents which are not purely relational. For example, hierarchial records are permitted and table-lookup operations dependent on an access method can be defined. Note that users are allowed to design and use a database without using any of the hierarchial features.

1.6 Interfaces

NOMAD supports three interfaces to the database:

1) Command Level Interface - A command at a time is interactively entered to the system.

2) Procedure Interface - The above commands can be combined with conditional and looping instructions.

3) Programming Language Interface. The NOMAD database can be referenced from FORTRAN, COBOL, PL/1 or BAL programs through a subroutine call mechanism.

The first Interface is the most general and supports the following capabilities:

(1) Data Schema Definition

(2) Query Language

(3) Database Altering

(4) Constraint Definition

(5) Database Generation and Regeneration

(6) Database Schema Redefinition and Re-naming

(7) Report Generation

(8) Data Entry

(9) Database Security

(10) Database Utilities

(11) Storage Structure Definition

(12) Database Dictionary

(13) A special purpose language

The Procedure and Programming Language interface can issue all of the commands in the command level interface and can thus perform all of the capabilities mentioned above. The distinctions between the three interfaces are discussed in Section 5.0. In Sections 2., 3. and 4., only the command level interfaces will be discussed. Note that interfaces can be used in on-line or batch modes.

1.7 Documentation

1) NOMAD Reference Manual
Form 1004-2, November, 1979

2) "NOMAD2 features and capabilities"
Form 1004Y, May, 1980

3) "Examples of NOMAD As a Relational Database System"
Daniel D. McCracken, April 17, 1979

1.8 General System Description

NOMAD is available through National CSS, Inc.'s time sharing service. Alternately, customers can obtain NOMAD on IBM compatible computer systems that run National CSS Operating Systems and on National CSS's mini-computers.

Some of the features available in NOMAD2 that are not in NOMAD include statistical analysis routines that take data from the database, perform analysis and optionally return that data in a form usable by NOMAD. In addition, basic data types such as arrays are allowed.

2.0 DATABASE CONSTITUENTS

The NOMAD system does not put bounds on what is considered 'one' database. Instead, NOMAD uses the term 'Database' to refer to a single relation or a set or relations defined at one time. Note that the relational operators can be used across these 'Databases' by having several open databases. In the discussion, a 'set of databases' will mean what is normally meant by a relational database.

2.1 General Description

The constituants of a NOMAD 'set of databases' are:

1) Databases - contain one or more, possibly unnormalized or hierarchial relations called 'MASTERS'.
2) Masters - contain one or more 'segments'. If multiple segments are present in a Master, they must be arranged in a hierarchy. Only the top level segments are called 'MASTERS'.
3) Segments - contain one or more attributes which are called 'items'.
4) Master/Segment Instance - One tuple with values in some

of the items.

5) Item - the attributes of a Master/Segment.

NOMAD does not support the basic concept of user defined Domains except as the fundamental types supported by the system (See Section 2.6). However, a 'member' constraint (see Section 2.6.1) can be used to restrict the set of possible values of an item. In addition, the 'limit' constraint (see Section 2.6.3) can be used to restrict the range of possible values of an item.

2.2 Database

2.2.1 Database Structures

At the schema level, relations can be added to the set of databases by using a 'SCHEMA' command. A schema can be named and can include other schemas and one or more hierarchial or normalized Masters. Note that the "Set of Databases" is unnamed. The 'DBADD' command can be used in a SCHEMA to logically group a set of related databases into one SCHEMA.

2.2.2 Constraints

The database schemas can be defined with zero or more passwords to control access to the database. These passwords are combined with schema procedures to control access to constituants within a database.

2.3 Master (=F.C. Relation)/Segment (=F.C. Relation)

2.3.1 Master Structure

A master is thought of as a hierarchial or normalized relation. A master is named and can have an access method specified. If the master is hierarchial, it is composed of segments which are composed of items. If the master is normalized, it is composed directly of items. An alias name can be given as a master or a segment.

2.3.2 Master Operations

Masters can be created in two ways. A Master can be created by defining a schema. Secondly, a Master can be dynamically created and populated as the output of selection, projection and joining operations on other Masters. Such implicitly created Masters can be used in retrieval operations, but cannot be updated via NOMAD commands. Note that operations on a hierarchial Master are made equivalent to the normalized expansion of the segments, (i.e. the items in higher level segments are repeated).

2.3.3 Master Constraints

Masters (and Segments) can be constrained in several ways. A key can be declared for the Master as for each segment and that key can be given a Unique/Not unique parameter. NOMAD enforces the uniqueness.

Retrieval procedures (RPROCs) and Update Procedures (UPROCs) can be used to define a boolean expression which must be true for the Master/Segment instances in the database. The boolean expression can contain items in the master and reference a password number which indicates that a given password must have been used to allow instances to be retrieved or updated. Note that items in a segment can be defined across database and master boundries so that the logical expression can in fact involve many masters. Violations on these constraints are treated as errors and simply reported to the user.

2.4 Views

Views are not explicitly supported in NOMAD. However, new schemas and subschemas can be defined which have masters based on items from other masters, creating in effect a dynamic view. Also, new databases can be created from selection, projection and joining operations and these new databases are in effect, static views.

2.5 Master/Segment Instances (=F.C. tuple)

2.5.1 Tuple Structure

The definition of a tuple is given in the definition of a Master/Segment. Missing values are allowed in attributes and are given the default value 'NOT AVAILABLE'. Note that NOT AVAILABLE is different than zero or blank.

2.5.2 Master/Segment Instance Operations

Individual instances of a Master/Segment can be obtained with logical and directional comments. The logical commands are LOCATE (with a boolean expression) and KEYED. Directional commands include NEXT, PREVIOUS, FIRST, LAST, STEP, TOP. The logical and directional commands can be freely intermixed. Instances in the database can be inserted, deleted, modified and printed.

2.5.3 Tuple Constraints

Constraints are defined with the Master/Segment.

2.6 Item (=F.C. Attribute)

2.6.1 Item Structure

Items can be named, with aliases, and must be one of the primary internal data types: 4 byte Real, 8 Byte Real, 2 byte integer, 4 Byte integer, 1 to 256 byte character field, 1 to 15 byte packed decimal field. In addition, a variety of 'NAME' and 'DATE' types are supported.

Items are defined with a display format, and optionally a heading and internal format.

Items can be defined with table look-up options to extract values for printing (DISPLAY), store values (ENCODE) and check for membership (MEMBER) using values in other Masters in the same schema. The use of these table look-up

options are restricted to keyed fields in other Masters.

Items can also be dynamically defined to be an expression involving other items in the Master.

2.6.2 Item Operations

Items can be compared if they are either numeric or alpha numeric for equality, not equality, less than, etc. Dates can also be compared. Character strings can be operated on with substring and other string manipulation operators. Numeric values can be operated on with the normal arithmetic operators. Special functions are provided to add/subtract months and years to dates.

2.6.3 Item Constraints

The Master/Segment constraints can be used to constrain items. In addition, Limits and Character String templates or masks can be specified when defining items. In addition, ENCIPHER options are provided to encode/decode data based on user specified keywords.

2.7 Domain

Not applicable.

3.0 FUNCTIONAL CAPABILITIES

In this section, four Masters will be used to illustrate the functional capabilities on NOMAD. The Masters are:

1) S - the supplier with items

SNO - the supplier number

SNAME - the supplier name

STATUS

CITY

2) P - the parts with items

PNO - the part number

PNAME - the part name

COLOR

WEIGHT

CITY

COST

3) SP - the supply with items

SNO - the supplier number

PNO - the part number

QTY - the quantity

4) C - the components with items

PNO - the part number

ICMP - the immediate components of PNO

In NOMAD commands, the names of items can be used by themselves if the names are unique in the database (or 'open databases'). If the names are not unique, a 'FROM mastername' can precede the item names.

3.1 Qualification

The NOMAD qualification is calculus oriented and the results of the qualification are broken into 'By-items' and 'Object-items'. The By-items dictate the sorting and grouping of the Object-items. The results of the qualifications are either the automatic input to the next command, a printed report, or a new database master file.

3.1.1 Restriction

NOMAD supports the following simple conditionals:

<, >, =, <=, >, =, >>, ><, >=. Mnemonic equivalents

(LT, GT, etc) can also be used. Items (Attributed) can be compared with constants, expressions and other Items.

These comparators can be used between all numeric types (automatic coercion), between alphanumeric types, between date types and/or name types.

Special comparators include: AMONG, BETWEEN and CONTAINS. The first two can be used on either numeric or alphanumeric data. The last operator can be used only on alphanumeric data. Arithmetic operators can also be used on date data types.

NOMAD supports the following logical connectors: AND, OR, XOR, NOT, IMPLIES, EQUIVALENCE.

These operators are combined to form a logical expression which is applied to each tuple in the master. Projection is done automatically by naming items in the By-items or Object-items. Selection in NOMAD has three flavors:

1) SELECT logical-expression. This command applies a restriction to the tuples in a MASTER which will be considered in the following NOMAD commands. For example,

```
SELECT FROM S STATUS = 10
COMMAND1
COMMAND2
```

would cause COMMANDs 1 and 2 to apply to S tuples which had a status of 10. Note SELECTS can be cleared, reset and/or nested. Also note that the 'FROM S' command is optional since 'STATUS' is a unique item name in the database.

2) WHERE logical-expression. The where clause is used to restrict tuples that are being listed or output to another master. For example:

List . . . where COLOR = 'RED' would list only the red part. The 'where' condition is in effect only for the duration of the command.

3) IF logical-expression. The If clause is very similar to the where clause. The distinction is not relevant to this analysis.

3.1.2 Quantification

NOMAD does not explicitly support universal quantification. Instead 'COUNT' and group by operators can be used to obtain the quantification results.

3.1.3 Set Operations

1) UNION between two masters can be achieved by creating an 'external' NOMAD file from one of the masters and loading that file into the other master. For example:

```
CREATE FROM MASTER:  ITEM1...ITEMN ON FILE1
LOAD MASTER2 READ FILE1
```

2) INTERSECTION, DIFFERENCE, AND EXTENDED CARTESIAN PRODUCT are achieved through the joining operations described in Section 3.1.4.

3.1.4 Joining

NOMAD supports six flavors of joining operations. We first review these operators and then discuss NOMADs solutions to the joining of a relation with itself.

The format of a NOMAD join is as follows:

$$\left\{\text{BY by-items}\right\}\ \text{object-items}\ \begin{bmatrix}\text{EXTRACT}\\ \text{SUBSET}\\ \text{REJECT}\\ \text{MERGE}\\ \text{EXTRACT ALL}\\ \text{SUBSET ALL}\end{bmatrix}\ \left\{\text{MATCHING m-items}\right\}\ \text{object-items}$$

These matching (joining) operations are basically 'equijoins' based on equal values between the by-items of one MASTER (=RELATION) and the m-items of the other MASTER (=RELATION). The six operations are discussed in turn for the following command:

$$\begin{bmatrix}\text{LIST}\\ \text{CREATE}\end{bmatrix}\ \text{BY FROM P PNO PNAME}\quad \text{OP}\quad \text{MATCHING FROM SP PNO QTY....}$$

=EXTRACT - This command results in each tuple in P together with the first (if any) tuple from SP with a matching PNO. Those tuples in P with no corresponding tuple in SP are included in the result but with a 'not available' value for QTY.

OP=SUBSET - This command results in the same tuples as 'EXTRACT' except that only the tuples from P that have corresponding SP tuples are included. Note that each tuple in P can still occur at most once in the result.

OP=REJECT - For this clause, the item QTY should not be present. The results of the create are all of the tuples in P that have no corresponding tuples in SP, i.e. the parts that aren't supplied. Note that this operator can be used to implement a set difference operator.

OP=MERGE - This operation creates one tuple for each tuple in P as does the EXTRACT operator. In addition, each tuple in SP that has no corresponding tuple in P generates one tuple in the result.

OP=EXTRACT ALL - This operation is similar to the EXTRACT. Each tuple in P contributes to one or more tuples in the output master. If n($\geq$ 1) tuples in SP correspond to a tuple in P, the tuple in P appears n times, each time with the appropriate QTY.

OP=SUBSET ALL - This operation corresponds to the mathematical definition of a relational join. Tuples appear in the output master if and only if the joining value is in both P and SP.

Notes:

1) The 'by-items' are all included in the output Master. The 'matching-items' are not. If there are name conflicts in the object lists, a 'NAMED' clause can be used to rename the item.

2) A MASTER can be joined with itself. For example,

LIST BY PNO FROM C REJECT MATCHING ICMP;

Lists those parts that have components but are not themselves components.

3) The internal type of a 'by-item' must be the same as the internal type of the corresponding 'matching-item'. However, a temporary new-item can be defined by:

DEFINE IN MASTER NEWITEM AS FORMAT EXP = ITEM;

the new-item format can be used to control the internal type and new-item can be used as a by or matching item.

4) Multiple items can be specified as by-items and matching items by repeating the key words 'BY' and 'MATCHING' respectively.

5) One LIST or CREATE command can have multiple matching operators if all of the joins are to be done on the same matching items. For example:

CREATE (BY PNO FROM SP SUBSET MATCHING PNO FROM P PNAME) SUBSET ALL MATCHING ICMP PNO NAMED FRED;

will join these relations since the join between any two relations is on the same item.

However, if one wanted to join S, SP, P with SNO being the linking item between S and SP and PNO being the link between SP and P; two commands would have to be used:

```
CREATE BY SNO FROM S SNAME CITY SUBSET ALL
        MATCHING SNO FROM SP PNO ON TEMP1;
CREATE BY PNO FROM TEMP1 SUBSET ALL MATCHING PNO
        FROM P PNAME CITY NAMED PCITY;
```

3.1.5 Nesting and Closure

Projects and Selects that are within individual MASTERS can be nested between the 'joining' operators. However, as illustrated in the previous section, the joining operators cannot be arbitrarily nested. Instead 'CREATES' must be used to create intermediate masters.

All of the operations are closed though, in that a CREATE can be used with any of the operators to generate a new master (= relation).

3.1.6 Additional Aspects of Qualification

A 'LOCATE' or 'KEY' command can be used to move to a particular record in the MASTER based on values in the MASTER. This 'logical' movement through a MASTER is useful if the MASTER is hierarchical in nature or in order to examine and/or update individual MASTER records. Note that these operations can be issued through the command level interface.

3.2 Retrieval and Presentation

3.2.1 Database Queries

Queries are expressed by using the keyword 'LIST' together with the qualification operators.

3.2.2 Retrieval of Information about Database Constituents

An SLIST (Schema List) command produces a schema like description on masters, items, defined items, selects currently in effect, user defined variables, and certain attributes of named constituents. The results of an SLIST can be stored

in a file and used with the selection and joining clauses.

3.2.3 Retrieval of System Performance Data

A utility DBCHK is provided which gives the storage utilization and blocking factors to indicate when a database should be reorganized. Such reorganization is primarily for garbage collection of disk space created by deleting instances of MASTERS/SEGMENTS.

3.2.4 Report Generation

NOMAD has an extensive report generation facility. The general format is:

LIST [By-item1 By-item2...][object-item1 object-item2...]

The report is ordered by the BY items. Sorting precedence is determined by the order of the items in the BY-list. Column headings and formats are defined at schema definition time but can be overridden at command time.

The report writer supports the following features:

- Retrieval, sorting and automatic formatting of the report
- Report functions such as sums, averages, maximums, minimums.
- Totaling and subtotaling
- User-controlled formatting
- Computations in the report
- ACROSS (horizontal listing)
- Titling, footings, group headings
- Screening and selection of data to be included in the report.

- Disjoint reports for non-related items
- Joining of databases with relational operators

3.2.5 Constraints

See the MASTER and item constraints defined in Section 2.

3.3 Alterations

The Alterations to the data base are either through the command Language interface one tuple at a time, or through a bulk 'LOAD' facility. Note that either method can also be initiated through the procedural or programming language interfaces. Note that for 'LOAD' commands, 'file' can be a user created file or the output of a CREATE.

3.3.1 Insert Facilities

New masters can be inserted into the database by issuing new 'SCHEMA' commands. New items (=Attributes) can be inserted into a MASTER(=Relation) with a 'SCHEMA REORG' command.

New instances of a MASTER(=Tuples) can be inserted in several ways:

1) INSERT name item1= . . . item2= . . . ;
   to individually insert instances.
2) PROMPT name; NOMAD prompts for values for each item.
3) LOAD name READ file; to LOAD multiple instances.

If some of the items are not given values, they default to N/A (Not Available). If a violation of a 'UNIQUE KEY' defined in the schema occurs, the instance is not added and an 'ON UNIQUE' condition is raised. The user can specify the action to take if certain conditions arise.

3.3.2 Delete

Masters can be deleted from the database by deleting their definition in the containing schema. Items can be deleted with a 'SCHEMA REORG' command.

Instances of a MASTER (= tuple) can be deleted by three methods:

1) Position to a particular instance through a LOCATE, KEY, or directional statement. Then DELETE name.

2) SELECT logical expression. Then DELETE name deletes all of the instances where the logical expressions were true.

3) LOAD name ONMATCH delete READ file; This command deletes all instances in name that have matching Key values in file.

3.3.3 Modify

Master and item definitions can be modified by a 'SCHEMA REORG' command.

Instances of MASTERS can be changed by three methods:

1) Position to a MASTER. CHANGE item1 = expression item2 = .; To change one instance.

2) SELECT logical expression. CHANGE item1 = expression ... To change all of the tuples for which the logical expression is true.

3) LOAD name ONMATCH CHANGE item1 item2...READ file. This command changes all instances in name that have matching KEY values in file.

3.3.4 Commit and UNDO

The system allows the user to issue the COMMAND SAVE

(=COMMIT) and/or RESTORE (=UNDO) a series of database alterations since the last SAVE or RESTORE. This feature can be bypassed with a 'SAVE ON' command or initiated with the 'SAVE OFF' command.

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

See Section 2

3.4.2 Sorting

During the SCHEMA definition time, KEYS can be specified for MASTERS and the MASTER is kept in sorted order on these keys.

During a LIST or CREATE, a 'BY clause' specifies the order of the tuples.

3.4.3 Library Defined Functions

AVERAGE, COUNT, NUMBER, FIRST, LAST, MAX, MEDIAN, MIN, STDDEV, SUM, UNIQUE, VAR are all supported.

3.4.4 User Defined Functions

The user can write FORTRAN or assemble functions which can be called from NOMAD. These functions can be used in derived item definitions.

3.4.6 Multi-tuple Alterations

These are supported. See Section 3.3

3.4.7 Grouping

The By-items in LIST and CREATE can be used to group instances of a MASTER. The BY items can be used with the Library functions to generate average salary by dept., etc.

3.4.8 Exception Handling Mechanisms

In the command level interface, the exceptions are reported to the terminal and/or to a file.

In the procedural interface, an 'ON condition' statement can be used to either generate a MESSAGE or execute a sequence of statements.

4.0 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

4.1 Definition Facilities

To define the sample database used in [DATE77], the following SCHEMA COMMAND can be given:

```
SCHEMA CJDATE;
MASTER SUPPLIER INSERT = KEYED(SNO, A);
       ITEM SNO        A2 ;
       ITEM SNAME      A5 ;
       ITEM STATUS     A2 ;
       ITEM SLOC       A6 ;
MASTER PART INSERT = KEYED(PNO, A);
       ITEM PNO        A2 ;
       ITEM PNAME      A5 ;
       ITEM COLOR      A5 ;
       ITEM WEIGHT     A2 ;
       ITEM PLOC       A6 ;
MASTER SHIPMENT INSERT = KEYED(SUPPNO, A, PARTNO, A);
       ITEM SUPPNO     A2 ;
       ITEM PARTNO     A2 ;
       ITEM QTY        99 ;
END;
```

4.1.1 Constituents of a Database Definition:

One NOMAD database, three MASTERs (= RELATION) and 12 items (= Attributes) are defined in the above schema.

4.1.2 Database Definition

The above example defines one database. Existing databases can be incorporated into this database at RUN time or SCHEMA definition time by a 'DBADD' command. All master names must be unique within one database.

4.1.3 MASTER (= RELATION) Definition

There are no specific limits on the number of items permitted for one MASTER. Item names must be unique within each segment in a MASTER. Thus if the MASTER is normalized item names must be unique.

The 'KEYED' clause specifies that a MASTER will be maintained in sorted order according to the values in the key. Optionally, the key can be declared 'UNIQUE'.

Options for MASTERS include:

1) ACCESS = opt - to specify whether READ/CREATE/CHANGE/DELETE can be used.

2) ALIAS = name

3) INSERT = Position

   or

   KEYED (item1 $\begin{bmatrix}A\\D\end{bmatrix}$,..., itemn $\begin{bmatrix}A\\D\end{bmatrix}$, $\begin{bmatrix}\text{unique}\\\text{notunique}\end{bmatrix}$

4) RPROC = rname

   rname $\vdots$ $\doteq$ logical expression

   to control read and insert access to a MASTER.

5) UPROC = uname

   uname $\vdots$ $\doteq$ logical expression to control alterations of a MASTER.

4.1.4 View Definition

Dynamic views, where no actual Data is stored can be defined by the DEFINE command.

Creates two dynamic items in SUPPLY based on items in other MASTERS. Note that PARTS and SUPPLIER must be KEYED and that only the 'First' SNAME for a given SNO would be used. Thus this view mechanism does not allow the full power of the relational Algebra.

Static views can be generated by a 'CREATE' command and can thus use the full power of the NOMAD joining operators. See Section 3.1.4.

4.1.6 MASTER Instance (= Tuple) Definitions

See Section 3.3

4.1.7 Item (= Attribute) Definition.

The general format of an item definition is:

ITEM item1 display-format [options];

The options include:

1) DISPLAY 'item2 FROM master1' to provide a table look up function using the value of name for <u>outputing</u> the item. The MASTER must be 'KEYED' on item1, although the name can be different.

2) ENCODE 'item2 FROM master1' to provide a table look-up function on <u>inputing</u> values into the Relation.

3) MEMBER 'Master1' when a value is internal for item1, it is checked to make sure there is an instance in Master1 with a key equal to the value.

4) ALIAS = name.

5) LIMITS = n:m or (a, b, c, n:m, z) - for alphanemeric,

numeric, date, or name data types.

6) MASK = 'Literal' to specify a template for a character string. i.e. MASK = 999-99-9999 for a Social Security Number.

7) ACCESS = options to specify READ/WRITE access permissions.

8) ENCIPHER/DECIPHER.

4.2 Generation Facilities

The SCHEMA commands can be given at any time from any of the interfaces. They can be intermixed with other NOMAD commands. For population of the database see Section 3.3.

4.3 Database Redefinition

4.3.1 Renaming Database Constituents

Item names, Aliases, and display formats, headings, limits, etc. can be changed with a 'SCHEMA CHECK' command.

4.3.2 Redefining Database Constituents

The internal formats of items, the number of items, the number of MASTERS can be changed with a 'SCHEMA REORG' option. Items can be added or deleted to MASTERS with this option. MASTERS can be added or deleted from a database with this option.

4.4 Database Regeneration and Reorganization

See Section 4.3.2. In general, reorganization is controlled by the user not the system.

4.5 Database Dictionary

An SLIST (Schema List) produces (prints as to a database readable file) descriptions of the database constituents:

mastername

itemname

MASTERS

DEFINES

SELECTS

SLIST can be used in the procedural interface to find the schema definitions of an item.

5.0 INTERFACES AND DBMS ARCHITECTURE

5.1 System Architecture

NOMAD supports three interfaces as shown in Figure 1.

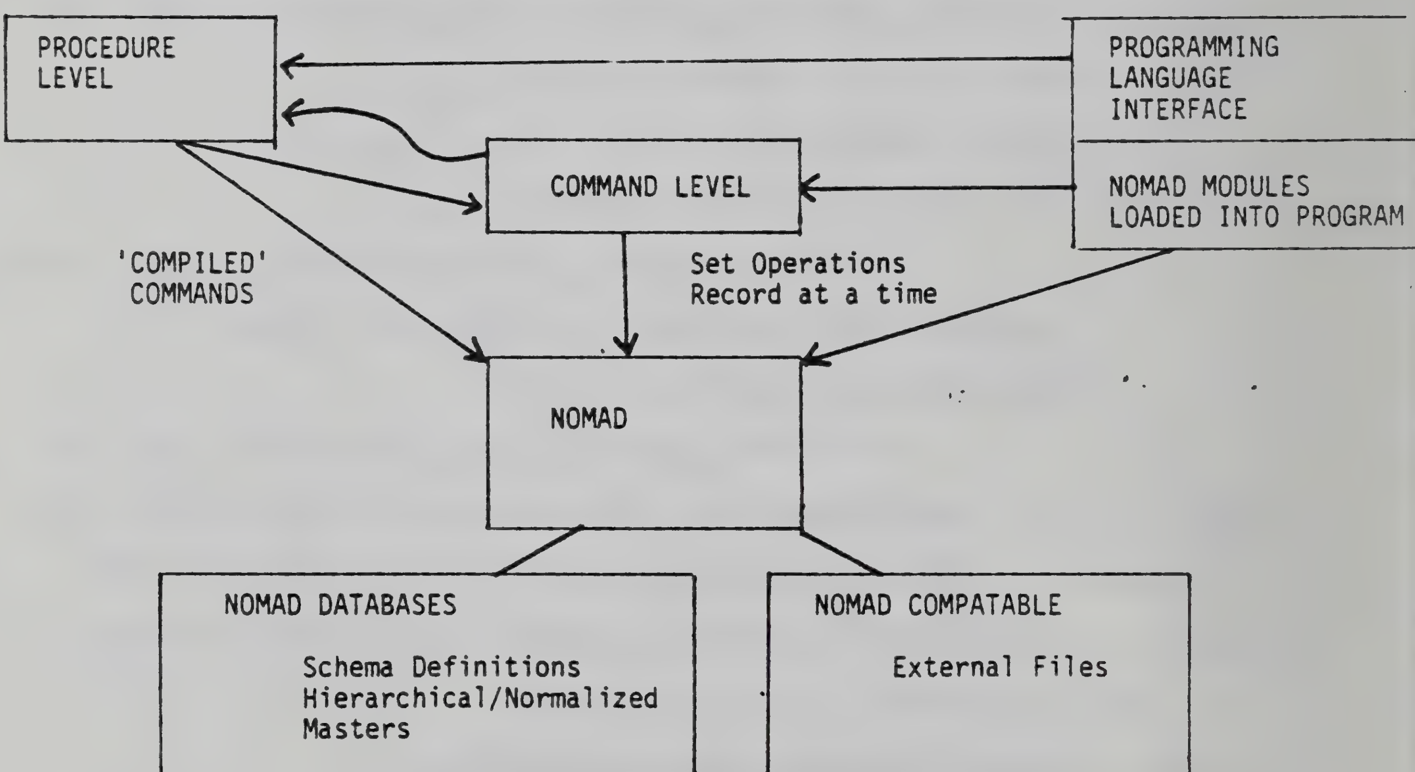

Figure 1. System Architecture

5.2 Interface Descriptions

5.2.1 Command Level Interface

This interface has been described in detail in Sections 2., 3., and 4.0.

5.2.2 Procedure Level Interface

Procedures are invoked with a 'NOMAD filename' command.

This interface is very similar to the command level interface with the following additions:

1) Flow of control constructs include:

'IF...THEN...ELSE'...' constructs, where a boolean condition can be specified and a different series of NOMAD commands can be executed depending on the TRUE/FALSE value of the boolean condition. These 'IF' statements can be nested.

'GO TO...' and LABELS.

'FOR Statement' to go through a loop a fixed number of times (NOMAD2).

2) Exception handling constructs:

'ON condition [message][commands]' allows the user to specify a set of NOMAD commands to be executed on a specific error condition. The error conditions can be a LIMIT, MASK, UPROC, UNIQUE violation.

'Command1 OTHERWISE [commands]' allows the user to specify a set of commands to be executed if Command1 fails.

3) System Variables: (This feature is actually available at the COMMAND Level interface but is more useful in this interface). A variety of system variables are set when commands are executed. These variables fall into three catagories: variables used for tracking exception conditions, variables used to indicate counts for changes, deletes, inserts, etc., and variables containing NOMAD parameters which in fact can be modified temporarily by

each user. These variables can all be used in 'if tests' to control the flow of the procedure.

4) Miscellaneous: In addition, procedures can be built into modules, compiled, traced and be switched into a conversational mode.

5.2.3 Programming Language Interface: NOMAD commands and procedures can be called through subroutine linkages from COBOL, PL/1, FORTRAN or BAL. Data from individual items or entire segments can be retrieved into user specified variables in the program. The system variables mentioned above can also be retrieved. A special command is provided to allow the program to query the data dictionary.

6.0 OPERATIONAL ASPECTS

6.1 Security

The security facilities were discussed with the constraints in Section 2.

6.2 Physical Integrity

6.2.1 Concurrency Control

Only one user is allowed to access a database at one time and use the SAVE/RESTORE commands. Multiple users can use the same database, but in that made, the affects of each command are realized immediately.

6.2.2 Crash Recovery

Note stated.

6.3 Operating Environment

6.3.1 Software Environment

NOMAD runs on the NCSS operating system.

6.3.2 Hardware Environment

NOMAD (and the NCSS operating system) require a minimum of 256K bytes of memory on an IBM plug compatable mainframe.

Those mainframes can be IBM 370/Model 138 and larger. In addition, NCSS will provide their own 3200 system to run NOMAD.

7.0 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS:

NOMAD illustrates the following advantages: simplicity, permits optimization, high level interfaces, efficient storage and retrieval potential, security and flexible data modeling. The realization of those advantages has been described in Sections 1-6 and is not repeated here.

The following features are also significant advantages of NOMADs Relational Model:

1) Normalization of a Hierarchy. This feature allows hierarchies to be used as though they were relations.
2) The concept of system variables as a method to communicate multiple results of set operations is useful.
3) The different joining operators add power to a relational system.
4) A consistent approach to missing values is attempted. The effects of missing values in joining is controlled by the user through the selection of the joining operator.

Two limitations of NOMAD should also be pointed out:

1) 'CREATE' only creates NOMAD compatable external files. These files can be used for subsequent retrieval but cannot be updated with NOMAD commands.
2) Data Independence. NOMAD allows considerable data independence from the physical representation of the data and from the access paths. However, the default item naming conventions can restrict the logical data independence. Under that convention, an item name can be used

without naming the MASTER if the item name is unique within the database. Suppose the item name 'FRED' was unique and used by 300 procedures. If a user adds a new MASTER with the name 'FRED' to the database, all 300 programs would have to be rewritten; note that none of the 300 programs needs to be concerned with the new master.

8.0 DATABASE APPLICATIONS

It is estimated that NOMAD is used by over 2000 users on NCSS timesharing service for over 200 applications and another 2000 - 2500 users on in-house dedicated systems for another 50 applications. Sales order entry, inventory control, environmental management, market research, sales analysis, personnel management, project control, resource allocation, project costing; securities tracking, budget tracking and analysis, portfolios analysis and management, investment analysis, acquisition and divestment analysis, cash management, insurance risk analysis, and state government bill tracking. It is interesting to note that most of the applications are analysis and management aids rather than some of the basic business systems such as payroll and general ledger.

One of the larger databases is about 200 megabytes and has over 50 Masters. Other databases have from 5 to 15 Masters. It is estimated that 75% of the applications make use of the relational-like table look-up facilities and that almost 50% of the applications regularly use the relational 'matching' commands.

The user experience with NOMAD and NOMAD2 was generally very favorable. One user indicated that the company's primary NOMAD application used a hierarchic database design. That application made extensive use of the table look-up facilities, but very rarely used the join or matching operators.

A user at a different site reported that most of the applications used normalized relations. Non-computer professionals were able to use these Masters and the joining operators after being shown or given a few standard procedures. For this site, NOMAD's flexibility was its most important feature. The latter user also commented that the 'MERGE MATCHING' and 'REJECT MATCHING' joining operators were the most heavily used.

ACKNOWLEDGEMENTS

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Feature Analysis
of
ORACLE*

by
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*Prepared while the author was at PRC Information Science Company, McLean, Virginia.

Preface

All examples in this feature analysis are based on the data base below:

S#	SNAME	STATUS	CITY
S1	Smith	20	London
S2	Jones	10	Paris
S3	Blake	30	Paris
S4	Clark	20	London
S5	Adams	30	Athens

P#	PNAME	COLOR	WEIGHT
P1	Nut	Red	12
P2	Bolt	Green	17
P3	Screw	Blue	17
P4	Screw	Red	14
P5	Cam	Blue	12
P6	Cog	Red	19

J#	JNAME	CITY
J1	Sorter	Paris
J2	Punch	Rome
J3	Reader	Athens
J4	Console	Athens
J5	Collator	London
J6	Terminal	Oslo
J7	Tape	London

SPJ

S#	P#	J#	QTY
S1	P1	J1	200
S1	P1	J4	700
S2	P3	J1	400
S2	P3	J2	200
S2	P3	J3	200
S2	P3	J4	500
S2	P3	J5	600
S2	P3	J6	400
S2	P3	J7	800
S2	P5	J2	100
S3	P3	J1	200
S3	P4	J2	500
S4	P6	J3	300
S4	P6	J7	300
S5	P2	J2	200
S5	P2	J4	100
S5	P5	J5	500
S5	P5	J7	100
S5	P6	J2	200
S5	P1	J4	1000
S5	P3	J4	1200
S5	P4	J4	800
S5	P5	J4	400
S5	P6	J4	500

From C. J. Date, 1977; An Introduction to Database Systems, Reading, Mass.: Addison-Wesley Publishing Company, pg 105.

CHAPTER 1

Introduction

1.1 Identification

ORACLE is an RDBMS marketed by Relational Software Incorporated, Menlo Park, California, that uses SQL, a query language developed by IBM.

1.2 Status

1.2.1 System

A prototype of ORACLE (Version 0) was released in 1978 under U.S. government contract. Two copies of ORACLE, Version 1, were delivered in June 1979. Version 2 of ORACLE is now installed in 20 sites. RSI's emphasis has been on performance. A summary of features promised for future releases is presented in Figure 1-1.

Figure 1-1

Capabilities Announced for Future Releases of ORACLE

Near-term

On-line monitor of system resources

Restart

Rollback

Privacy control

Limited closure capability on hierarchic relationships

Forms-transaction processing

Concatenated keys

Usage statistics

User-controlled clustering in physical storage

Aliases for attribute names

Comments on attribute definitions in data dictionary

"date" data type

Long-term

Trigger

Assertion

Snapshot

Word-processing

1.2.2 Applications

ORACLE is intended to be a system for naive users requiring a flexible DBMS. RSI promotes ORACLE as especially suitable for applications requiring

security granularity (to be implemented in future releases) or a DBMS that runs on several mainframes. Applications under development include several defense-oriented data bases.

At present, RSI is looking for customers who are familiar with the relational model and willing to tolerate the inconveniences of using a new product. For marketing reasons RSI is anxious to attract large customers and OEM customers. At the same time, RSI is interested in the single-user market.

1.3 System Backround

RSI began development of ORACLE in 1977 and demonstrated a prototype relational system in 1978. The first copy of the system was delivered in June 1979. External interfaces to ORACLE resemble those of System R; however, ORACLE employs a different internal structure.

1.4 Overall Philosophy

RSI states that "The ultimate objective of a data base system is to manage all the data which encompasses the related activities of an organization while remaining flexible and easy to use."

1.5 Essential Relational Characteristics

Currently, attributes used to join relations must be indexed; RSI has announced that this restriction will be relaxed in a future release.

In addition, the set operators union, intersection, difference and extended cartesian product are not supported; updates cannot be performed on user views; and semantic integrity constraints are not supported.

The following capabilities are promised for future releases: set operators, semantic integrity constraints, i.e., assertions and triggers, and updates using views.

1.6 Interfaces

Interface Type	ORACLE Interface
(1) Database schema definition	Definition statement in SQL
(2) Query language	SQL, mapping-oriented language based on relational calculus
(3) Database altering	SQL; Interactive Application Facility
(4) Constraint definition	None implemented at present
(5) Database generation and SQL regeneration	
(6) Database schema redefinition and renaming	EXPAND TABLE, ADD COLUMN, and EXPAND COLUMN statements in SQL
(7) Report Generation	ORACLE Report Writing
(8) Data entry	Separate Load utility; Interactive Application Facility interface
(9) Security definition, monitoring control	SQL
(10) Database Control (utility):	
load, dump	IMPORT/EXPORT utilities
backup, restore, recovery, monitoring	Promised for future release
(11) Definition of storage structure, index and access paths	SQL
(12) Database dictionary	System-maintained, queried using SQL
(13) Special purpose language	FTP

1.7 Documentation

Documentation for ORACLE consists of the ORACLE USERS GUIDE, containing the following manuals:

ORACLE INTRODUCTION

SQL LANGUAGE REFERENCE

SQL LANGUAGE EXAMPLES

HOST LANGUAGE INTERFACE

TERMINAL INTERFACE

INTERACTIVE FORMS PROCESSOR

UTILITIES

MESSAGES AND CODES

ORACLE INSTALLATION GUIDE

CHAPTER 2

Database Constituents

2.1 General Description

The constituents of an ORACLE database consist of the database, relations (also called tables), views, tuples (also called rows and records), and "domains" (also called columns and fields). Individual data items within a logical record are called "attributes". ORACLE does not have a term for domains as used in the feature catalog. In this document, however, "attribute" and "domain" are used with the same meaning as in the feature catalog.

These constituents are related as follows. A relational database consists of relations of possibly different types. A relation consists of tuples of identical type. A view is derived from one or more relations by means of projection and qualification operations. A tuple consists of item values of possibly different types. A domain is defined in terms of a user-defined data type.

2.2 Database

2.2.1 Database Structure

An ORACLE database consists of a set of relation definitions, which are stored in system-maintained relations, a set of stored tuples for each relation, and a set of views (virtual relations defined on base relations). A data base is named by assigning the desired name to the file when the data base is created.

2.2.2 Database Operations

2.2.3 Database Constraints

At present no capability for database constraints is implemented. Global assertions and triggers have been announced for future versions of ORACLE.

2.3 Additional Database Constituents

2.4 Relation

2.4.1 Relation Structure

A relation is defined as a two-dimensional table of data items, thus the predominant perception of a relation is as a table of rows and columns. Relations within a database are assigned unique names at the time of definition.

Duplicate tuples are permitted, although the system will enforce a uniqueness requirement for a primary key if it is specified in the definition. Attribute order is significant. Aliases for relation names can be assigned in view definitions.

2.4.2 Relation Operations

Not applicable

2.4.3 Relation Constraints

ORACLE supports a uniqueness requirement for any attribute the user wishes to use as a key. Primary keys must be indexed. In addition, the system will reject NULL values in inserted or updated tuples.

The first attribute defined for a relation must be assigned a value when a tuple is inserted.

2.5 Views

2.5.1 View Structure

Views are defined as dynamic virtual tables comprising a selected portion of the database. Views are defined by assigning a name to a stored retrieval command. Views are derived by selecting qualified tuples from base relations. Keys are inherited from base relations.

2.5.2 View Operations

Views are defined in a view definition statement that can include any valid retrieval and selection operations. They may be referenced like base relations in retrieval commands; at present, update operations may not reference views.

2.5.3 View Constraints

Views can be used to implement access control on the basis of access to columns and/or to selected tuples. Views also provide a means for restricting type of access.

2.5.4 Additional Properties of Views

2.6 Tuple

2.6.1 Tuple Structure

A tuple in ORACLE is defined implicitly by the relation definition. It consists of a set of values and/or nulls corresponding to the relation definition. Unique key values may be used for identifying tuples, but are not required.

2.6.2 Tuple Operations

Tuple structure is implicitly defined by relation definition statements. An instance of a record consists of a set of associated stored values for the attributes named in the relation definition. A tuple may be required to have a unique key. Tuples may be retrieved one at a time using the FETCH command in the Host Language Interface.

2.6.3 Tuple Constraints

The first attribute defined in the relation must always be valued. A uniqueness constraint can be imposed on tuples by specifying a uniqueness requirement for an attribute in the definition (concatenated keys are not presently supported). Constraint violations result in rejection of the insert or update command.

2.6.4 Additional Properties of Tuples

2.7 Attribute

2.7.1 Attribute Structure

An attribute (column) is defined as a field in a relation for values of a specified data type.

Attributes are assigned unique names within the relation when the relation is defined. Alias capabilities for attribute names are promised for future versions of ORACLE. Aliases will be assigned in view definitions. The only distinguished attribute values in ORACLE are nulls.

2.7.2 Attribute Operations

Attributes can be manipulated in selection and retrieval operations using the relational comparison operators, arithmetic operators, and aggregate functions; arithmetic operators and aggregate functions can also be used in insertion and update operations. Attributes have the same compatibility requirements as the primary data types.

2.7.3 Attribute Constraints

Not applicable

2.7.4 Additional Properties of Attributes

Not applicable

2.8 Domain

2.8.1 Domain Structure

ORACLE supports domain definition only as specification of a field size and pre-defined data type from the set of available data types. The following external data types are available: variable-length alphanumeric string and floating-point decimal.

2.8.2 Domain Operations

Not applicable

2.8.3 Domain Constraints

Not applicable

2.8.4 Additional Properties of Domains

Not applicable

CHAPTER 3

Functional Capabilities

3.1 Qualification

Qualification in ORACLE is calculus-oriented. Qualification results may be thought of as a relation populated with qualified rows.

Qualification can be used with retrievals, update and deletions, e.g.,

```
SELECT  SNAME
FROM    S
WHERE   CITY = 'PARIS';
/
UPDATE  S
SET     STATUS = 10
WHERE   CITY = 'PARIS';
/
DELETE   S
WHERE   S# = 'S7';
/
```

3.1.1 Restriction

The following operators can be used in simple conditions:

SYMBOL	DEFINITION
=	the equal comparison operator
~=	the not equal comparison operator
>	the greater than comparison operator
>=	the greater than or equal comparison operator
<	the less than comparison operator
<=	the less than or equal comparison operator
BETWEEN	the range comparison operator (The range is specified as a pair of constants, expressions or attributes connected by AND.)
IN	the set inclusion operator. IN tests a field for inclusion in a set of values.
AND	the boolean operator AND
OR	the boolean operator OR
X...	true for the string beginning with X
NULL + (exp_1,exp2)	if value of exp_1 is null, use value of exp2

Stored values, constants, and nested expressions can be used in selection criteria. NULL can be specified to test for an unvalued field.

The truth tables used for evaluation of logical expressions are:

AND	T	F	?
T	T	F	?
F	F	F	F
?	?	F	?

OR	T	F	?
T	T	T	T
F	T	F	?
?	T	?	?

NOT	
T	F
F	T
?	?

Nulls cause arithmetic expressions to be evaluated as false unless an alternate treatment for NULLs has been specified. Expressions can be combined into boolean expressions using AND and OR, e.g., "Print the number and names of all suppliers who supply project in quantities greater than 500".

```
SELECT  S#,SNAME
FROM    S, SPJ
WHERE   SPJ.S#=S.S#
AND     QTY > 500;
/
```

3.1.2 Quantification

ORACLE supports neither universal nor absolute quantification. Universal quantification is planned for a future release.

3.1.3 Set Operations

Set operations are not directly supported; they can be accomplished using combinations of other SEQUEL operators.

3.1.4 Joining

Joins in ORACLE are handled by means of restriction in selection criteria subject to the following constraints:

- o Reflexive joins required using a different table name for each table reference to the base relation.
- o At present items used for specifying joins must be indexed.
- o Up to 255 relations can be joined

Only equi-joins are supported. Outer-joins are supported.

3.1.5 Nesting and Closure

Logically, selection in ORACLE produces a relation populated with qualified tuples. (Retrieval and alteration operations also produce relations.)

Simple qualification criteria can be nested to express more complex criteria, e.g., "Find the parts that come in either red or blue and have a weight less than 15."

```
SELECT PNAME
FROM P
WHERE (COLOR = 'RED' OR COLOR = 'BLUE')
     AND WEIGHT <15;
/
```

The result of one qualification can be further qualified. This is expressed by embedding a projection in a WHERE clause, e.g., "Find the names and cities of suppliers who are located in cities where there are projects."

```
SELECT SNAME, CITY
FROM S
WHERE S.CITY IN
     SELECT J.CITY
     FROM J;
     /
```

Closure capabilities for hierarchical relationships are available.

3.1.6 Additional Aspects of Qualification

Not applicable

3.2 Retrieval and Presentation

3.2.1 Database Queries

A retrieval is perceived to return a table populated with qualified tuples. Retrievals may result in any number of tuples, i.e., all qualified tuples are retrieved. Retrieved tuples may be sorted before they are displayed. When selection criteria are combined with OR, a tuple that meets each condition is operated on twice, unless UNIQUE is specified in the projection (SELECT) clause.

User-defined arithmetic operations and ORACLE-supplied functions may be used with retrieved values.

3.2.2 Retrieval of Information about Database Constituents

Schema information, stored as system-maintained tables, can be retrieved using SQL retrieval commands, e.g., "Print the names of attributes in the SPJ table."

```
SELECT *
FROM COL
WHERE TABLE = 'SPJ';
/
```

3.2.3 Retrieval of System Performance Data

No system performance data is provided by ORACLE at present. Monitoring capabilities have been announced for a future release.

3.2.4 Report Generation

Report-writing facilities are available with a word processor. RSI is developing an easier-to-use report writer.

3.2.5 Constraints and Limitations

Elimination of duplicate copies of a single tuple and collection of usage statistics have been announced for future releases.

3.3 Alteration

3.3.1 Insert Facilities

Inserted data are perceived as new rows in a stored table. Single tuples (complete and incomplete) can be inserted into ORACLE base relations, using SQL, e.g.,

```
INSERT INTO SPJ: <S2, P6, J3, 500>;
/
INSERT INTO SPJ (S#, P#): <S2, P6>;
/
```

Attribute names must be specified when a value is not supplied for every attribute in the relation. The leftmost attribute in the relation definition, however, must always be valued. NULLs are not accepted when an attribute is defind as NONULL.

The results of a query can be used in an insert operation, e.g., "Create a tuple in S for any supplier who supplies a part to a project and is not already listed in S."

```
INSERT INTO S (S#):
SELECT UNIQUE S#
FROM SPJ
WHERE SPJ.S# NOT IN
SELECT UNIQUE S#
FROM S;
/
```

Inserts can also be done using the Forms Transaction Processor.

3.3.2 Delete Facilities

Tuples can be deleted from a base relation, e.g., "Delete from the S relatio n any supplier who does not supply a part to a project."

```
DELETE S
WHERE SPJ.J3 NOT IN
SELECT J#
FROM J;
/
```

3.3.3 Modify Facilities

One or more attributes in a stored tuple may be modified. Either a constant or the result of an arithmetic expression can replace a stored value, e.g., "Change the minimum quantity for all parts supplied to projects to 200."

```
UPDATE SPJ
```

```
SET QTY = 200
WHERE QTY < 200;
/
```

NULL may be substituted for a stored value.

User-supplied parameters are perceived as individual values for named attributes in SQL commands or FTP commands.

It is not currently possible to use the results of a retrieval from a different tuple to modify a value.

3.3.4 Commit and Undo Facilities

None available.

3.4 Additional Functional Capabilities

3.4.1 Attribute and String Operations

ORACLE supports addition, subtraction, multiplication, and division in selection, retrieval, and modify operations.

3.4.2 Sorting

Retrieved tuples can be sorted before they are displayed, using a total concatenated sort field of up to 255 characters. Each field within the sort field can be sorted in ascending or descending order.

3.4.3 Library Functions

ORACLE supports the aggregate functions MIN, MAX, COUNT, SUM, AVERAGE.

3.4.4 User-defined Functions

User-defined functions are not supported at this time.

3.4.5 Transactions

Transaction capabilities are available. Locking can be specified for tables or rows.

3.4.6 Multi-tuple Operations

All tuples meeting selection criteria can be modified with a single command; likewise, all qualified tuples are deleted with one command. Insertions that copy one or more tuples from one relation to another are supported.

3.4.7 Grouping

Tuples can be grouped by value for one or more items for use with aggregate functions.

3.4.8 Exception-handling Mechanisms

ORACLE notifies the user of errors or exceptional conditions by means of return codes in the Host Language Interface and error messages in the self-contained interface.

CHAPTER 4

Definition, Generation, and Administration Facilities

4.1 Definition Facilities

The following definition is used in the discussion below.

```
CREATE TABLE S
    S# (CHAR (6) IMAGE),
    SNAME (CHAR (15)),
    STATUS (NUMBER),
    CITY (CHAR (15));
    /
CREATE TABLE J
    J# (CHAR (6) IMAGE),
    JNAME (CHAR (15));
    CITY (CHAR (15));
    /
```

```
CREATE TABLE P
    P# (CHAR (6) IMAGE),
    PNAME (CHAR (15)),
    COLOR (CHAR (8)),
    WEIGHT (NUMBER);
    /
CREATE TABLE SPJ
     S3 (CHAR (6) IMAGE),
     P# (CHAR (6) IMAGE),
     J# (CHAR (6) IMAGE),
     QTY (NUMBER);
     /
DEFINE VIEW PROJSUPP AS
    SELECT UNIQUE J.J#, J.JNAME, S.S#, S.SNAME
    FROM J, S, SPJ
    WHERE J.J# = SPJ.J#
      AND S.S# = SPJ.S#
    ORDER BY J.J, S.S#;
/
```

4.1.1 Constituents of a Database Definition

A database definition consists of relation definitions, which contain attribute definitions, and view definitions.

4.1.2 Database Definition

A database may have any number of relations.

4.1.3 Relation Definition

A base relation is defined by assigning it a unique name and defining each of its attributes. A relation may have up to 255 attributes, any of which may be key (no unique key is required). The first defined attribute is treated by the system as a primary key; it must be defined as NONULL and it must be indexed. Current maximum field width is 255 characters; the maximum width for all attributes in a tuple is 64K characters.

4.1.4 View Definition

Views are defined by assigning view status and a view name to a retrieval command, which may or may not include selection criteria. The only restrictions on view definition are restrictions on retrievals. Views may be referenced like other relations in retrieval operations, but cannot be used in alteration operations.

Future releases will permit users to assign alias attribute names in views.

4.1.5 Tuple Definition

Properties of tuples are implicitly defined in the relation definition.

4.1.6 Attribute Definition

Attributes are defined in relation definitions. Attribute names must be unique within a relation. Domains are defined as part of the attribute definition by specifying maximum field width (up to 255 characters) and character type. The definition may include a specification that the attribute be valued for every tuple. A uniqueness requirement may also be specified.

4.1.7 Domain Definition

Domains can only be defined in terms of the picture specified in an attribute definition. ORACLE supports alphanumeric and floating point decimal date types.

4.1.8 Definition of Additional Database Constituents

Not applicable

4.1.9 Generation Facilities

Once a file is created, ORACLE automatically generates a relation when the relation is defined.

4.2 Database Redefinition

4.2.1 Renaming Database Constituents

No renaming capability is supported.

4.2.2 Redefining Database Constituents

Relation definitions can be expanded to include additional attributes; attribute field widths will be subject to expansion in future releases.

New views may be defined at any time. No other redefinition capabilities are provided. Definition changes entail modification of the dictionary tables; however, no restructuring of the database is required as a result of definition changes.

4.3 Database Regeneration and Reorganization

4.3.1 System-Controlled

ORACLE dynamically reuses space and re-organizes portions of the database as alterations to the database are processed. No complete restructuring of the database is ever initiated.

4.3.2 DBA-Controlled

No DBA control over database reorganizaton or regeneration is provided.

4.4 Database Dictionary

The ORACLE data dictionary consists of system-maintained base relations and views. The tables are:

Table Name	Type	Attribute
SECURITY	Base relation	KEY, ENTITY, COLUMN, GRANTOR, OWNER, ACCESS
XREF	Base relation	NAME, TABLE
VIEWDEF	Base relation	VIEW, LINE, TEXT
DICTIONARY	Base relation	NAME, TYPE, OWNER
COLUMNS	Base relation	TABLE, COLUMN, DATATYPE, LENGTH, IMAGE, NONULL, COLID
TAB	View	NAME, TYPE, CREATOR, GRANTEE
COL	View	COLUMN, TABLE
TABLES	View	TABLE
USER	Base relation	NAME, ID, PASSWORD, GRANTOR
DBS	Base relation	NAME, EXTENTS, SIZE, SECFLAG, OWNER
EXTENT	Base relation	DB NAME, FILE, EXTNUM, SIZE
DTAB	Base relation	TABLE, COMMENT
DTABLES	View	TABLE, TYPE, CREATOR, GRANTEE
DCOL	View	TABLE, COLUMN
PRIVS	View	TABLE, COLUMN, GRANTOR, ACCESS
COLDEF	View	TABLE, COLUMNS, DATATYPE, LENGTH, IMAGE, NONULL
VIEWS	View	VIEW, TEXT

VIEW XREF	View	VIEW, TABLE
USERS	View	USER, OWNER
GRANTS	View	TABLE, COLUMN,GRANTEE, ACCESS

The VIEWDEF table contains the SQL commands defining the view. The user can query the dictionary using SQL retrieval commands, e.g., "List the definition of columns in the PROJ table."

```
SELECT     COLUMN, DATATYPE, LENGTH, IMAGE, NONULL
FROM       COLUMNS
WHERE      TABLE = 'PROJ';
/
```

PROJNO	NUMBER	8	UNIQUE	YES
PNAME	CHAR	10	NON-UNIQUE	NO
BUDGET	NUMBER	8		NO
EMPCNT	NUMBER	8		NO

OR 5-1

CHAPTER 5

Interface and DBMS Architecture

5.1 System Architecture

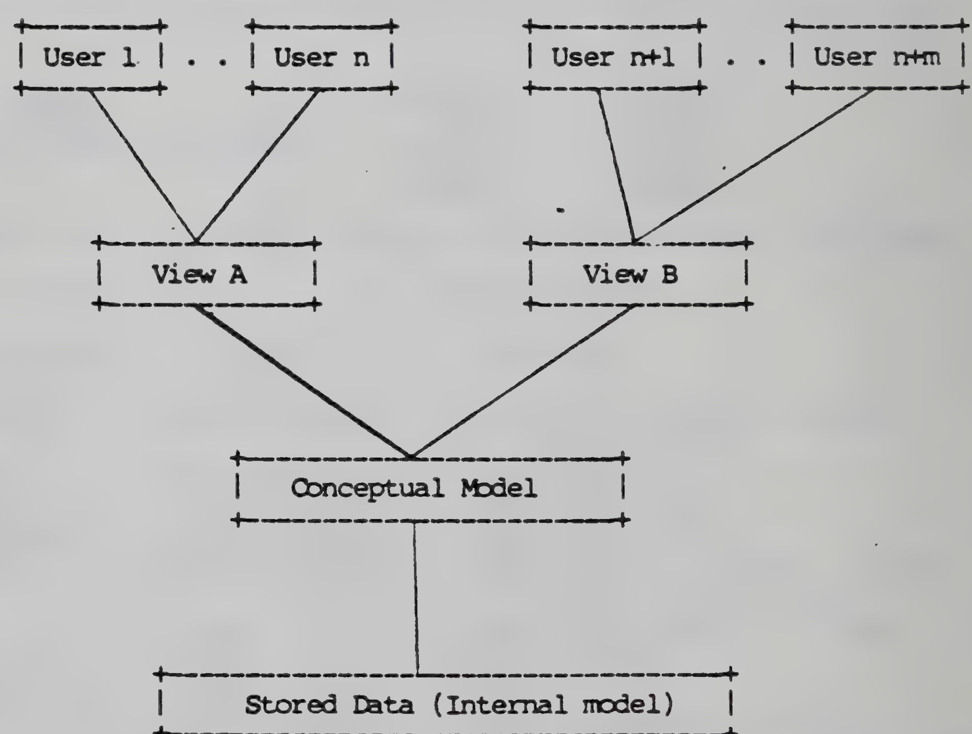

Figure 5-1 ORACLE ARCHITECTURE

5.2 Interface Description

5.2.1 SQL

SQL is a self-contained language for data definition, selection, query, and update. It can be used to define relations and attributes, to insert, modify, or delete tuples, and to retrieve relations or projections on relations. Relations are treated as tables.

SQL commands are linear and use English keywords. Selection is based on the relational calculus, with criteria specified in a WHERE-clause. The language is user-driven and is intended for ad hoc query and update. SQL can be used on a stand-alone basis; SQL commands can also be embedded in user-written programs.

5.2.2 Interactive Application Facility (IAF)

Interactive Application Facility is a system-driven fill-in-the-blank type of interface for tuple insertion update, and queries. It can be used on a stand-alone basis. The DBA defines forms which are presented to the user for keyboard input.

5.2.3 Host Language Interface

ORACLE interfaces to host language by means of program calls, using SQL statements embedded in a host programming language as a data sublanguage. Programs log on to ORACLE, open data bases, pass SQL statements to ORACLE, execute those statements, close data bases, and exit. Communication takes place via a LOGON Data Area defined in the user program and specified in the logon call. Programs may substitute program variables into SQL statements.

When data is delivered to a program one tuple at a time, ORACLE places a return code in the cursor data area after each call. A single user program may have multiple SQL cursors open at one time.

5.2.4 User Friendly Interface

The User Friendly Interface (UFI) is the interface between a terminal user and ORACLE. UFI handles communications with the DBMS, routing of output and scheduling for printing, and writing SQL commands to a file. UFI also provides a very limited line-oriented text-editing capability.

OR 6-1

CHAPTER 6

Operational Aspects

6.1 Security

6.1.1 Access Control

Privacy control is maintained by means of password and views. Thus, access could be limited to any set of values in the data base that can be specified in a SQL command. The person defining a base relation or a view can grant or revoke the following privileges to other passwords: read, insert, delete, update, add columns, create indexes, define assertions or triggers, execute compiled programs, and grant privileges to other users. Access to a view is constrained by authorization for underlying relations.

Any user can define and maintain private relations. The person defining a relation can perform any operation, on that relation, including granting and revoking privileges.

6.2 Physical Integrity

6.2.1 Concurrency Control

The lowest concurrency granularity is at the row level. That is, as SQL statements are executed, rows are only locked while they are being actually operated upon.

If a user wishes to read or update consistent data, he can issue the following command

```
BEGIN TRANSACTION <table name> {READ  } ,<table,> ...
                               {UPDATE}
```

Each table specified will be locked until the END TRANSACTION command is issued. The READ modifier is issued by someon who wishes to read consistent data. The UPDATE modifier is issued by someone who wishes to update a table(s) and wishes to block other updates.

Release 3 will allow roll back recovery to tne beginning of a transaction.

6.2.2 Crash Recovery

No automatic crash recovery capabilities are provided. The user can back up and restore a database manually, using the IMPORT/EXPORT utility; however,

no logging or undo capability exists.

Audit capabilities are promised for a future release.

6.3 Operating Environment

6.3.1 Software Environment

ORACLE is relatively independent of executive, control, or operating systems. The operating system is used only for interfacing to peripherals, such as secondary storage.

6.3.2 Hardware Environment

ORACLE can be used on the following hardware:

IBM
- Memory Requirement:
- CPU's
  - System 360 (model 40 and above)
  - System 370 (all models)
  - 303X (all models)
  - 4300 (all models)
- Operating Systems
  - VM
  - MIS, SVS, OS/MVT
  - OS/VSI, OS/MFT
  - DOS/VSE, DOS/VS, DOS

DEC
- Memory requirements: 80K words
- CPU's
  - PDP-11 series (model 23 and above)

OK 6-7

VAX-11 series (all models)

Operating Systems
RSX-11M, IAS, UNIX and others
VAX/VMS, VAX/UNIX

ORACLE also requires secondary storage (disk space) and terminal or batch input and output facilities.

PASCAL/R
System Evaluation*

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June 1981

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*Also released as PASCAL/R Memo 63-81.

1. Introduction

1.1 Identification

PASCAL/R is a relational DBMS involving the programming language PASCAL/R, an extension of PASCAL. PASCAL/R is an ongoing research and development product at the Fachbereich Informatik, Hamburg University (principal investigator: J. W. Schmidt).

1.2 Status

1.2.1 System

PASCAL/R is operational since 1978. It is currently (fall 1980) active at the University of Hamburg, at the ETH Zurich, at NBS in Washington D.C., at DEC in Maynard, Massachusetts, and at the University of Toronto.

1.2.2 Applications

- Database Research and Development
- Implementation of Database Systems and Languages

- Teaching of Database Concepts
- Database Design
- Database Applications

1.3 System Background

The PASCAL/R system development started as an extension of a PASCAL compiler and its runtime system. The query evaluation subsystem is based on an algorithm proposed by F.Palermo (IBM San Jose). Proposals similar to the PASCAL/R approach are, e.g., PLAIN (T. Wasserman), RIGEL (L. Rowe), THESEUS (J. Shapiro), ASTRAL (T. Amble et al.). PASCAL/R is implemented on a DECsystem-10 under the operating system TOPS 10.

The PASCAL/R system is written in PASCAL.

1.4 Overall Philosophy

PASCAL/R considers a database as an (external) variable that can be accessed by (compiled or interpreted) programs.

The PASCAL/R language provides the data structure relation, operations and control structures for relations and full standard PASCAL. The major design objective of PASCAL/R is to integrate relation structures and PASCAL data and control structures as closely as possible. This effort seems worth-while for two reasons.

Firstly, many programming tasks may benefit directly from the new set-like data structuring facility, from its general content-based selection and test mechanisms, and from its altering operators. Secondly, since database models concentrate on data structuring, querying, and alteration they are, in general, not "algorithmically complete". Therefore, both programming tools, database models and programming languages, have to be applied cooperatively to solve database-intensive applications.

The PASCAL/R system is considered to be a framework within which the essential concepts of programming languages and database models can be taught and studied with respect to their interaction, trade-off, and implementation effort.

1.5 Essential Relational Characteristics

PASCAL/R is "relationally complete". It supports

- the structural aspects of the relational model, including the domain concept;
- insert, update, and delete operations; and
- a calculus-oriented data selection language.

1.6 Interfaces

The interfaces to the PASCAL/R system provide the following capabilities :

- Database Schema Definition including (limited) Constraint Definition
- Interactive Interface to Database Querying and Altering Facilities
- Database Generation
- Definition of Access and Storage Structures
- Database Dictionary
- Database Utilities: Save, Restore, Reorganize
- The High Level Programming Language PASCAL/R

- Report Generator

- Screen Definition Facilities

1.7 Documentation

J.W. Schmidt: 'Some High Level Language Constructs for Data of Type Relation', ACM Transactions on Database Systems, Vol 2, No 3, (September 1977).

J.W. Schmidt, M. Mall: 'PASCAL/R Report', Bericht Nr. 66, University of Hamburg, W. Germany (January 1980).

W. Lamersdorf, J.W. Schmidt: 'Specification of PASCAL/R', Berichte Nr. 73 and Nr.74, University of Hamburg, W. Germany (July 1980).

M. Jarke, J.W. Schmidt: 'Evaluation of First-Order Relational Expressions', Bericht Nr. 78, University of Hamburg, W. Germany (June 1981).

1.8 General System Description

The PASCAL/R Relational Database System provides the following capabilities:

- definition of relations, relation keys, domains;

- generation of relational databases, i.e. collections of relations;

- a calculus-oriented query mechanism and a specific key-based selection mechanism for relation element (=tuple) selection;

- an interactive interface;

- an interface to PASCAL and to PASCAL/R, an extension of PASCAL by a data structure relation, relation-valued and quantified expressions, relation altering operators

and a control structure controlled by relations;

- utility programs for the definition of access paths and the analysis and reorganization of databases.

2. Database Constituents

2.1 General Description

Term translation table:

System Term	Feature Catalogue Term
database	database
relation	relation
relation element	tuple
(relation element) component	attribute
(relation element) component identifier	attribute name
(relation element) component type	attribute type = domain

A relational database consists of relations of possibly different type. A relation consists of relation elements (=tuples) of identical type. A relation element consists of relation element components (=attributes) of possibly different type. Relation element components are denoted by component identifiers; component types (=domains) define the set of legal component values and operators; component values are considered to be atomic, i.e., they can not be further decomposed by database operations.

2.2 Database

2.2.1 Database Structure

A structure of type database consists of a fixed collection of (base) relations and is identified by its name.

2.2.2 Database Operations

Databases can be defined (schema definition), generated, and reorganized. A database is defined by a PASCAL/R type definition; a database is generated and reorganized by privileged utility programs.

2.2.3 Database Constraints

Database constraints are defined on the relation, relation element (=tuple), and element component (=attribute) level.

2.3 Relation

2.3.1 Relation Structure

A structure of type relation consists of elements (=tuples) of identical type.

A relation may be perceived as an <u>array-like</u> structure with a key-based selection mechanism for relation elements; a relation may also be perceived as a <u>set-like</u> structure with first-order predicates for subset selection.

The value of a relation is always a subset of the Cartesian product of the component types defining the relation element components.

The relation constraints (see 2.3.3, relation key) does not permit the existence of two or more elements in a relation with identical values for the key components.

Relations have fixed identifiers; Relation names can be redefined by the formal/actual parameters of PASCAL/R.

2.3.2 Relation Operations

Operations defined on relations are those for qualification (see 3.1), querying (see 3.2) and altering (see 3.3).

Major design goals for the operations were:

- formal rigor and uniformity:

  relational structures and operations are defined in terms of first-order predicate calculus and set theory.

- conceptual soundness:

  relational concepts are defined in terms of programming language concepts (data structures, selectors, types, variables, Boolean and relational expressions etc.).

The elements (=tuples) of a relation are not ordered.

However, an order on the relation elements (=tuples) is induced by the order on the key value set (as defined by the type of the key component); in case of a composite key a lexicographic order on the key values is assumed. This order can be exploited by a set of relation handling procedures (see 3.2.1(1)).

2.3.3 Relation Constraints

A relation is constrained by its key. The key is defined by one or more relation element component identifiers. The system enforces that there are no two or more

elements in a relation with the same value for the key components. In other words, the key constraint guarantees that every relation element can be identified uniquely by its key value.

Altering the value of a relation variable must not violate the relation type, i.e. the relation element type and the key. PASCAL/R tries to detect as many type violations as possible at compile time; possible type violations that cannot be eliminated at compile time are indicated by a warning and are resolved by standard runtime actions (see 3.4.8).

2.4 View

A PASCAL/R database does not support views.

However, within a PASCAL/R program local relations can be defined that may have certain properties of static views. Local relations can be manipulated by the qualifying (see 3.1), querying (see 3.2), and altering (see 3.3) capabilities defined for relations.

2.5 Tuple

2.5.1 Tuple Structure

In the current version of PASCAL/R, relation element (=tuple) types have to be defined by the data structure <u>record</u> (only "flat" records without variants are allowed). The data type <u>record</u> is a structure consisting of a fixed number of components, possibly of different type.

Keys are defined at the relation level.

There exists a selection mechanism for unique relation element (=tuple) qualification, based on key values (see 3.1.1).

2.5.2 Tuple Operations

PASCAL/R provides a test operation to check whether an element (=tuple) with a given value exists in a relation or not (see 3.2.1 (3)).

The value of a relation element (=tuple) can be changed by an assignment operation. Depending on the value of the relation element and on the value of the expression assigned the effect of an assignment operation is equivalent to an update, insert, or delete operation on relations (see 3.3).

The general selection mechanism selects each relation element (=tuple) that fulfills a given predicate; a selection may also be used to control a for-statement (see 5.2); thus, selected elements (=tuples) can be accessed and processed one-at-a-time by the body of the for-statement.

2.5.3 Tuple Constraints

The type of a relation element (=tuple) is given by the relation element type definition. A selected relation element (=tuple), e.g., rel[kval], inherits the additional constraint that the value of its key component, e.g., k, must not be altered.

The relation element (=tuple) constraints are part of the relation element type definition; constraint violations are regarded as type violations.

2.6 Attributes

2.6.1 Attribute Structure

A component (=attribute) of a relation element (=tuple) is perceived as an object of unstructured type (=domain) and is identified by a name (component identifier (=attribute name)).

2.6.2 Attribute Operations

The operations on element components (=attributes) are defined by the component type (=domain) (see 2.7.2).

2.6.3 Attribute Constraints

The constraints on element components (=attributes) are defined by the component type (=domain) (see 2.7.3).

2.7 Domain

2.7.1 Domain Structure

Component types (=domains) are identified by names and have the structure of sets of unstructured values.

The following basic value sets are provided : integer, real, Boolean, character, ascii, strings of fixed length. New value sets may be defined by enumerating their elements.

No distinguished domain values like null, unknown etc. are defined.

2.7.2 Domain Operations

The assignment operator is defined for each component type (=domain); additionally, the following operators are defined:

- for string, char, ascii, Boolean, integer, real, enumeration, and subrange: comparison operators (= , <> , <= , >= , < , >),
- for Boolean: logical operators (<u>and</u>, <u>or</u>, <u>not</u>),
- for integer and real: arithmetic operators (+, -, *, /, <u>div</u>, <u>mod</u>) and additional functions provided by PASCAL.

Component types (=domains) are the basis of compatibility for relation element components (=attributes): only components defined by component types with identical names are compatible.

2.7.3 Domain Constraints

Constraints on integer value sets and enumeration value sets can be defined by upper and lower bounds (subrange types).

3. Functional Capabilities

3.1 Qualification

PASCAL/R mechanisms for selections are content-oriented. Relation elements are selected by means of selection predicates that have to be fulfilled by the value of the selected elements.

PASCAL/R has a specific selection mechanism that is based on the equality of key values; it leads to unique elements and fits best in an array-like perception of relations.

PASCAL/R also has a general selection mechanism that is based on first-order predicates; it leads to a variable number of selected elements and fits best into a set-like perception of relations.

Selection predicates usually have relation elements amongst their operands, and, thus, have to correspond with the type definition of relation elements.

Example of a Database Type (=Schema) Definition
===

```
{see C.J. Date : An Introduction to Database Systems,
     2nd Edition, page 52}


type cityname       =  packed array of [1..15] char;
     suppliername   =  packed array of [1..20] char;
     partname       =  packed array of [1..20] char;
     quantity       =  integer;
     creditstatus   =  0..999;
     weightunits    =  0..9999;
     colortype      =  (red,blue,yellow,green,black);
     suppliernumber =  1..99999;

     company        =  record snr: suppliernumber;
                              sname: suppliername;
```

```
                         status: creditstatus;
                         city: cityname
                  end;

     item       = record pnr: integer;
                         pname: partname;
                         color: colortype;
                         weight: weightunits;
                         city: cityname
                  end;

     order      = record snr: suppliernumber;
                         pnr: partnumber;
                         qty: quantity
                  end;
     companies  = relation <snr> of company;
     items      = relation <pnr> of item;
     orders     = relation <snr,pnr> of order;

     business   = database suppliers: companies;
                           parts: items;
                           shipments: orders
                  end;
```

Example of a Database Declaration
==================================

```
Var  mybusiness    : business;
```

3.1.1 Restriction (=Selection)

Free variables can be defined to denote the elements of (range) relations. The scope of a free variable, i.e., the context in which it is known, is a subsequent Boolean expression (selection predicate). Free variables, e.g., r, and selection predicates, e.g., p, form selections, e.g. ### each r in rel : p(r) ### that select those elements of the relation, rel, that fulfill the selection predicate.

Any Boolean expression containing free variables, PASCAL expressions, comparison or logical operators (see 2.7.2) (or quantified expressions, see 3.1.2.) is a legal

selection predicate.

Given its key value, e.g., kval, any element of a selection, e.g., rel, can be selected by an index-like selection mechanism, e.g., rel[kval].

Example:

```
   ... mydatabase.parts[4711] ...
   ... with mydatabase do     {with-statement see 5.2}
       begin
              ... parts [ 46*100 + 111 ] ...
              ... shipments [ 100, 4711 ] ...
              ... each p in parts : (p.pname = 'cardreader') or
                                    (p.weight >= 10)  ...
       end
```

3.1.2 Quantification

Existentially and universally quantified variables can be defined to denote the elements of (range) relations. The scope of a quantified variable is the subsequent Boolean expression (matrix predicate). Provided r denotes an element variable and p is a matrix predicate, then <u>some</u> r <u>in</u> rel (p(r)) and <u>all</u> r <u>in</u> rel (p(r)) are legal quantified expressions that evaluate to a Boolean value indicating whether or not the predicate p holds for at least one or for all elements of the (range) relation, rel.

Any Boolean expression constructed out of quantified variables, PASCAL expressions, comparison or logical operators, or quantified expressions forms a legal matrix predicate. Quantified expressions can also be used as selection predicates (see 3.1.1.).

Absolute quantification is not supported (there is, however, a counting function size(re), see 3.2.1).

Example:

```
  with mydatabase do
      begin ...
      ...   each p in parts : ( p.color = blue ) and
            some sp in shipments ( sp.pnr = p.pnr ) ...
      end
```

3.1.3 Set Operations

For set-like operations see 3.2 and 3.3.

3.1.4 Joining

Since quantified expressions can be used as selection predicates a relation can be restricted dependently upon data in another, possibly different, relation (see example 3.1.2.). For the construction of new relations by joining relations, see 3.2. .

3.1.5 Nesting and Closure

A quantified predicate (see 3.1.2) can be used as the matrix of another predicate (see 3.1.1 and 3.1.2), and a relation expression (see 3.2.1) can be used as a range relation. Therefore, quantified and relational expressions, i.e., predicates and queries can be nested arbitrarily (see however 3.2.5).

3.2 Retrieval and Presentation

3.2.1 Database Queries

The selection mechanisms of section 3.1 form the basis of the PASCAL/R query facilities.

The result of a query against a PASCAL/R database is

either

1. a single relation element (1-element query), or

2. a relation value containing a number of relation element (=tuple) values (N-element query), or

3. a Boolean value (Boolean query).

1. 1-Element Queries:

A selected relation element, rel[kval], is a variable and can therefore be regarded as a (simple) expression evaluating to the value of the selected element.

Example:

```
   var thispart: item;   ...
   with mydatabase do
   begin   ...
        thispart := parts[4711] ;  ...
   end
```

Five relation handling procedures (low, next, this, high, prior) select at most one relation element from the relation variable, e.g., rel, given as the first procedure parameter. If the element exists, it is assigned to a second parameter, e.g., relem, and a Boolean standard function, eor(rel), becomes false; if the element does not exist, the Boolean function eor(rel) becomes true and relem remains unchanged.

low (rel,relem)	selects the element of the relation variable which has the lowest key value. The order on key values is given by the order on the value set underlying the key component type; in case of a composite key a lexicographic order on the key values is assumed.
next (rel,relem)	selects the element of the relation variable which has a key value next highest to the current key value in the variable relem.
this (rel,relem)	selects the element of the relation variable which has the key value equal to the current key value in the variable relem.

high (rel,relem) — selects the element of the relation variable which has the highest key value.

prior (rel,relem) — selects the element of the relation variable which has the key value next lowest to the current key value in the variable relem.

Example:

```
   var thispart: item;   ...
   with mydatabase do
   begin   ...
        thispart.pnr := 4711;
        next ( parts, thispart ) ;   ...
   end
```

2. N-Element Queries:

The relation elements selected by the general selection mechanism, each r in rel : p(r) , can be converted into the relation (-valued) expression, [each r in rel : p(r)] . The value of this expression is equal to the subrelation of rel that fulfills the selection predicate, p.

Relation expressions are generalized to provide :

```
Projection :        [ <r.f,...r.g> of each r in rel : p(r) ] ;
Cartesian Product:  [ <rl.f,...rn.h> of each rl in rell, ...
                      each rn in reln : p(rl,...rn) ]
Union :             [ each rl in rell : pl(rl),...,
                      each rn in reln : pn(rn) ]
```

In the latter case, the relation element types of rell,...reln have to be compatible. (For a different use of the general selection mechanism see 5.2)

Example:

```
   var shipped parts: items;   ...
   with mybusiness do
   begin   ...
        shipped_parts := [ each p in parts :
                             some sp in shipments
                             (sp.pnr = p.pnr) ] ;     ...
```

```
   end
```

Example:

```
   var local_supply: relation <sname,pname> of
                     record sname: suppliername;
                            pname: partname
                     end ;      ...
   with mybusiness do
   begin   ...
   local_supply := [ <s.name,p.name> of each s in suppliers,
                      each p in parts : s.city = p.city ]
   end
```

3. Boolean Queries:

Quantified expressions return Boolean values.

Example:

```
   var all_squares_are_red :  Boolean ;   ...
   with mybusiness do
   begin   ...
        all_squares_are_red := all p in parts
        ( (p.color = red) or not (p.shape = square) ); ...
   end
```

Note, that this Boolean query is equivalent to

```
    all_squares_are_red :=
        all p in [each p in parts: p.shape = square]
              ( p.color = red ) ;
```

The element test operator, *in*, tests whether or not a given element exists in a relation; the set-like operators =, <>, >, >=, <=, < test relation equality or inclusion.

Example:

```
   var thispart: item;
       thispart_exists: Boolean;   ...
   with mybusiness do
   begin   ...
          thispart_exists := thispart in parts ;   ...
   end
```

Note that this Boolean query is equivalent to
```
   thispart_exists := parts [ thispart.pnr ] = thispart ;
```
and to
```
   thispart_exists := some p in parts (p = thispart) ;
```
It differs, however, from
```
   thispart_exists := parts [ thispart.pnr ] in parts ;
```
The latter query is equivalent to
```
   thispart_exists := some p in parts (p.pnr = thispart.pnr);
```

Example:
```
  var theseparts: items;
      these_parts_exist: Boolean;   ...
  with mydatabase do
  begin    ...
          these_parts_exist := theseparts <= parts;   ...
  end
```

PASCAL/R's query facility is considered to be relationally complete.

Absolute quantification is not directly supported; there exists, however, a function, size(re), counting the number of elements in a relation expressions, re.

Example:
```
   var three_red_parts :  Boolean ;   ...
   with mydatabase do
   begin   ...
       three_red_parts :=
            size ( [each p in parts : p.color = red ] ) = 3
   end .
```

3.2.2 Retrieval of Information About Database Constituents

The database schema is stored in a data dictionary organized as a PASCAL/R relational database. Privileged users (e.g. the DBA) are allowed to access the dictionary in order to retrieve and partially alter schema information.

3.2.3 Retrieval of System Performance Data

Information about the physical organization is stored in the dictionary, e.g. on

- storage utilization (allocated vs. utilized storage space),
- access paths and storage structures,
- distributions of relation component values (see 4.4.1),

and can be accessed by privileged users (e.g. the DBA).

3.2.4 Report Generation

Relation expressions can be listed on printers and displays.

Example:

```
   list ( [ <s.name,p.name> of each s in suppliers,
            each p in parts: s.city = p.city ] ) ;
```

This list command may produce the output

```
   abel     axe
   abel     bolt
     :       :
   zille    wrench
```

Standard programs for output formatting (report generation) exist.

3.2.5 Constraints and Limitations

The current implementation is restricted to

- five (free and quantified) variables per expression
- 15 subexpressions, e.g.,
  ... <u>and</u> (s.city = p.city) ...

within relation expressions and quantified expressions.

3.2.6 Additional Aspects of Retrieval and Presentation

Facilities for automatic screen layout exist.

3.3 Alteration

Altering operators on relations are considered as generalized assignment operators.

In the array-like perception an altering operation replaces the value of a relation element by a new value specified as an expression of the relation element type.

In the set-like perception an altering operation replaces the value of a relation by a new value specified as a relation expression.

3.3.1 Insert Facilities

Relations can be altered by insert operations.

In the array-like perception a single element is inserted by assigning a (record) expression to a relation element that is not yet inserted.

Example:

```
with mybusiness do
  if not parts[4711] in parts
  then parts[4711] :=
        < 4711, 'cardreader', blue, 20, 'washington' > ;
```

The above PASCAL/R expression constructs a record value of type item from its component values using the PASCAL/R record constructor <...> .

In the set-like perception elements are inserted into a relation by assigning a (relation) expression to a relation variable.

Example:
```
  var insparts: item;   ...
  with mybusiness do
  begin
     parts := [ each p in parts : true ,
                each i in insparts :
                 not some p in parts (i.pnr = p.pnr) ]
  end
```

The Value of the above relation expression is the union of the old value of the relation variable and the set of new elements to be inserted.

An equivalent shorthand notation using the insert operator, :+, reads

Example:
```
  var insparts: item;   ...
  with mybusiness do
  begin   ...
     parts :+ insparts ;
  end
```

Using the insert operator the insertion of a single element reads

Example:
```
  with mybusiness do
    parts :+ [ <4711,'cardreader',blue,20,'washington'> ] ;
```

3.3.2 Delete Facilities

Relations can be altered by delete operations.

In the array-like perception a single element is deleted by assigning the "void" (record) expression (i.e., the empty record constructor, < >) to an existing

relation element.

Example:

```
  with mybusiness do
    if parts[4711] in parts
    then parts[4711] := < >  ;
```

In the set-like perception elements are removed from a relation by assigning a (relation) expression to a relation variable.

Example:

```
  var delparts: item;   ...
  with mybusiness do
  begin   ...
     parts := [ each p in parts : not some dp in delparts
                        ( p.pnr = dp.pnr ) ]
  end
```

The value of the above relation expression is the set difference of the old value and the set of elements to be deleted.

An equivalent shorthand notation using the delete operator, :-, reads

Example:

```
  var delparts: item;   ...
  with mybusiness do
  begin   ...
     parts :- delparts
  end
```

Using the delete operator for the deletion of a single element reads

Example:

```
  with mybusiness do
       parts :- [ parts[4711] ] ;
```

3.3.3 Modify Facilities

Relations can be altered by modify operations.

In the array-like perception a single element is modified by assigning a (record-) expression to an existing relation element.

Example:
```
  with mybusiness do
    if parts[4711] in parts
    then parts[4711] :=
         < 4711, 'parfume', yellow, 1, 'cologne' > ;
```

Note, that individual components of relation elements can be modified

Example:
```
  with mybusiness do
    if   parts[4711] in parts
    then parts[4711].weight := 2;
```

In the set-like perception relation elements are modified by assigning a (relation) expression to a relation variable.

Example:
```
  var modparts: item;   ...
  with mybusiness do
  begin   ...
     parts := [ each p in parts :
                   not some mp in modparts (p.pnr = mp.pnr),
               each mp in modparts :
                   some p in parts (mp.pnr = p.pnr) ]
  end
```

The value of the above relation expression is defined by set difference and set union.

An equivalent shorthand notation using the modify operator, :_, reads

```
var modparts: item;   ...
with mybusiness do
begin   ...
     parts :_modparts
end
```

Using the modify operator the modification of a single element reads

Example:

```
with mybusiness do
parts :_ [ < 4711, 'parfume', yellow, 2, 'cologne' > ];
```

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

The arithmetic operators are presented in 2.7.2 .

Because strings are defined as arrays of characters, PASCAL/R has (limited) facilities for manipulating strings.

3.4.2 Sorting

Relation elements are not sorted. However, through the relation handling procedures low, next, high, prior (see 3.2.1(1)) the order defined by the key values can be exploited to gain an ordered access to relation elements.

3.4.3 Library Functions

PASCAL/R provides the PASCAL standard functions and a function

3.4.4 User Defined Functions

Within the PASCAL/R language environment the user can define any kind of private functions; libraries can be built up by means of external procedures and functions.

3.4.5 Transactions

The PASCAL/R system is a single-user system. A new version that allows concurrency through "transaction" procedures with (selected) relations as read and read/write parameters is under development.

3.4.6 Multi-Tuple Alterations

The relation altering operators, :=, :+, :_ (see 3.3.1 to 3.3.3) may alter more than one relation element (=tuple) at a time.

3.4.7 Grouping

3.4.8 Exception Handling Mechanisms

The PASCAL/R compiler tries to detect as many type violations (=exceptions) as possible. In case a decision cannot be made without runtime information warnings are generated at compile time.

A specific class of runtime type violations occurs if the value of a relation expression does not fulfill the key constraint defined on a left-hand-side relation variable. A collision of this kind is resolved by a standard coercion mechanism: The system selects one element out of every multiplicity of elements of the right-hand-side relation expression that has the same value in what is defined to be the key of the left-hand-side variable. The fact that a coercion between relation expression and relation variable occurred is reported to the user through the standard status variable, coerced.

4. Definition, Generation And Administration Facilities

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

A PASCAL/R database definition (=schema definition) contains the definition of the

- database type,
- relation types,
- relation element (=tuple) types, and
- relation element component (=attribute) types (=domains).

This information is stored in a database dictionary (logical part).

In addition, a PASCAL/R database definition contains information about

- the (primary) indexes to be maintained for relations,
- the blocksize of the files implementing relations,
- expected and actual distribution of component values (see 4.4).

This information is stored in the database dictionary (physical part).

4.1.2 Database Definition

A database type (=logical schema) definition associates a database type identifier with a database type. A database is defined by the PASCAL/R data structure database and specifies for each database component (=relation) its type and a component identifier.

Example:

```
  { type (=Schema) definition }
  type business = database suppliers :  companies;
                           parts     :  items;
                           shipments :  orders
                  end;
```

Technically, a database is defined by a utility program that reads a database type (=logical schema) definition from a text file and initializes the logical part of a database dictionary.

A database type definition is not completely defined until the constituting relation types (e.g., companies) are defined.

A database type definition does not require the introduction of type identifiers for the relation types.

Example:

```
  type business = database
                     suppliers : relation ... end ;
                     parts     : relation ... end ;
                     shipments : relation ... end
                  end ;
```

(see example 4.1.3)

4.1.3 Relation Definition

A relation type definition associates a relation type identifier with a relation type. A relation type is defined by the PASCAL/R data structure relation and specifies the relation element type as well as the relation key.

```
type
  companies = relation < snr > of company;
  parts     = relation < pnr > of item;
  shipments = relation < snr,pnr > of order;
```

A relation type is not completely defined until the constituting relation element (=tuple) type (e.g. item) is defined.

A relation type definition does not require the introduction of type identifiers for the relation element (=tuple) types.

Example:

```
type companies = relation < snr > of record ... end ;
     parts     = relation < pnr > of record ... end ;
     shipments = relation < snr,pnr > of record ... end ;
```

(see example 4.1.5).

4.1.4 View Definition

A PASCAL/R database definition defines base relations only.

4.1.5 Tuple Definition

A relation element (=tuple) type definition associates a relation element type identifier with a relation element type.

The relation element type is defined by the PASCAL data structure _record_ (only "flat" records without variants and with unstructured components are allowed), and specifies for each relation element component (=attribute) its type and a component identifier.

Example:

```
  type item = record pnr    : integer;
                     pname  : partname;
                     color  : colortype;
                     city   : cityname
              end
```

The relation element type is not completely defined until the constituting component types (=domains) (e.g. colortype) are defined.

The relation element type definition requires the introduction of type identifiers for the component types (=domains); a component type identifier is either user-defined (see 4.1.7) or it is one of the built-in identifiers integer, real, Boolean, char, ascii.

4.1.6 Attribute Definition

A relation element component (=attribute) is defined as part of the relation element type definition (see 4.1.5). The component definition specifies a component (=attribute) type (=domain, see 4.1.7) and a component identifier.

4.1.7 Domain Definition

A relation element (=tuple) component (=attribute) type (=domain) definition associates a component type identifier with a component type. A component type (=domain) is defined by a PASCAL "simple type", i.e., either by

- a <u>standard type</u>, i.e., integer, real, Boolean, char, ascii
  Example:
  ```
  type quantity = integer;
  ```
- a <u>scalar type</u>, i.e., an ordered set of values given by an enumeration of the identifiers which denote these values
  Example:
  ```
  type colortype = ( red, blue, yellow, green, black );
  ```

- a subrange type, i.e., a subrange of a scalar type, or of the types integer or char given by the indication of the first and last value in the subrange.
  Example:
  ```
  type creditstatus = 0..30;
  ```

4.1.8 Definition of Additional Database Constituents

Technically, a database is defined by means of an interactive utility program that reads the logical part of a data dictionary (i.e., the database type definition) and asks the (privileged) user for information about access paths and storage structures (see 4.1.1) to be stored in the physical part of the data dictionary.

4.2 Generation Facilities

A PASCAL/R database is generated by a utility program that accesses a database dictionary and creates an empty database according to the schema, access paths, and storage structures as defined in the dictionary.

An identifier is associated with the database.

4.3 Database Redefinition

4.3.1 Renaming Database Constituents

Within a PASCAL/R program the identifier for the database, the database type, the database relation types, the relation element types, and the element components can be redefined.

4.3.2 Redefining Database Constituents

An existing database can be redefined only with respect to its access paths.

4.4 Database Regeneration and Reorganization

4.4.1 System-Controlled

The database system maps string values that exceed an implementation-dependent length into code numbers of fixed length. This mapping is order preserving and may lead to collisions, i.e., depending on the actual distribution of string values different strings may be mapped into the same code number. Collisions of this kind are resolved by system- controlled recoding. The user does not realize how data are represented.

4.4.2 DBA-Controlled

A database can be regenerated to provide new or to cancel existing access paths. A database can be reorganized to minimize the amount of storage occupied. A database may also be reorganized by redefining the mapping between string values and code numbers (see 4.4.1) to achieve a desired distribution of code numbers. The DBA can ask for reports on the physical status of the database.

4.5 Data Dictionary

The database definition is stored in a database dictionary. The database dictionary is perceived as a PASCAL/R database and can be accessed by privileged users.

5. Interfaces and DBMS Architecture

5.1 System Architecture

The Relation Selection System (RSS) evaluates N-element and Boolean Queries. RSS optimizes query evaluation by scanning a (range) relation only once and by minimizing the size of intermediate results; basically, this is achieved by rearranging the order in which subexpressions and quantifiers are evaluated.

The Relation Access System (RAS) performs the 1-element access using existing access paths.

```
                     *******************
                     *      U S E R    *
                     *  interactive or *
                     *    batch mode   *
                     *******************
                           o       A
                           o       *
                      _____V_______V____
     oooooooooooooooo| PASCAL/R  Code:  |
     o               |  interpreted or  |             Interpreter/
     o  *************|     compiled     |             Compiler
     o  *            |__________________|
     o  *              o      A      o
   __V__V___     _______o______V______o___      ___________
  |         |    | ___V___      ____V___  |    |           |
  |Integrity|    ||       |<***>|       |<****>|Operating- | Run-
  |         |    || R S S |     | R A S | |    | and       | time-
  |  Check  |    ||_______|oooo>|_______| |ooo>|File-System| system
  |_________|    |________________________|    |___________|
        A                          A             A
        o                          *             *
       oooooooooooooo              *             *
                    o              *             V
                ____o______________V_____     ******
               | logical    | physical   |  *         *
               |-------------------------|  * ******* * Stored Data
               |     Database            |  *         *    and
               |        Dictionary       |  * Data    *    Data
               |_________________________|  *         * Description
                             A              *         *
                             *                *******
                ______________V___________
               |                         |
               | RDB - Definition,       |
               |     - Generation, etc.  |
               |_________________________|
                         A   A
                         o   *
                         o   V
                  *******************
                  *                 *
                  *      D B A      *         ooooo> : flow of control
                  *                 *
                  *******************         *****> : flow of data
```

Figure 5.1 PASCAL/R System Architecture

5.2 Interface Descriptions

The PASCAL/R system provides three user interfaces:

1. Database / PASCAL/R-program
2. Database / interactive user
3. Database / privileged user (DBA) .

1. PASCAL/R-programs:

The program parameter mechanism binds a PASCAL/R database as a global variable to a PASCAL/R program.

Example:

```
  program copyitems ( mybusiness, orderlist ) ;
  type   ...  { see 3.1 }
       item       = record  ...  end ;   ...
       business   = database ... ;
                                parts : relation <pnr> of item;
                    end;
  var  mybusiness : business ;
       orderlist : file of item ;
  begin      ...
       rewrite (orderlist) ;
       with mydatabase do
       for each p in parts : some sp in shipments
                (p.pnr = sp.pnr) do begin orderlist↑ := p;
                                         put (orderlist)
                                  end
  end .
```

PASCAL/R extends the programming language PASCAL essentially by

- a data structure relation,
- the operations introduced above for (database) relations,
- a control structure controlled by the general relation selection mechanism.

The only difference between PASCAL/R <u>database relations</u> and PASCAL/R <u>program relations</u> is their

lifetime. Database relations are explicitly generated and dropped by a privileged user (DBA); the lifetime of program relations is determined by the lifetime of the PASCAL/R block in which they are declared. Treating database and program relations alike means in particular:

- Expressions over database variable constituents can be assigned to program variables (database queries);

- Expressions over program variables can be assigned to database relations (database alterations).

- Boolean queries can control program statements (if..then..else..; while..do..; repeat...until..;)

Example:
```
    var thispart: item;   ...
    with mydatabase do
    begin  ...
       if not some sp in shipments
             ( sp.pnr = thispart.pnr )
       then parts :- [ thispart ]
    end
```
Example:
```
    var theseparts : items ;   ...
    with mydatabase do
    begin  ...
      if not some sp in shipments
           ( some tp in theseparts (sp.pnr = tp.pnr) )
      then parts :- theseparts
    end
```

An essential construct of PASCAL/R is a for control structure controlled by a relation element selection, each r in rel : p(r) (see 3.1). That way the elements can be processed one at a time by any PASCAL statement.

Example:
```
  var max_weight_shipped : weightunits ;
  begin  ...
    max_weight_shipped := 0 ;
    with mydatabase do
      for each p in parts :
          some sp in shipments (p.pnr = sp.pnr)  do
      if   max_weight_shipped <  p.weight
      then max_weight_shipped := p.weight ;
  end
```

The with-statement of PASCAL is generalized so that database relations can be denoted without prefixing them by the database identifier, e.g.,

Example:
```
   with mybusiness do
   begin ...  parts  ... end;
```

is equivalent to

```
   mybusiness.parts
```

Relations can also be declared as local variables in PASCAL/R procedures; they can be passed as (read and read/write, i.e., value and reference) parameters; so, procedure statements can be used to form compound database query and altering operations.

Example:
```
  procedure average_weight ( parts: items;
                             var avg: weightunits );
   var a: weightunits;
   begin    a := 0;
      for each p in parts : true  do
          a := a + p.weight;
      avg := a div size(parts)
   end
```

6. Operational Aspects

6.1 Security

6.1.1 Access Control

Currently, access to a PASCAL/R database is controlled only through the standard feature of the operating system.

6.2 Physical Security

6.2.1 Concurrency Control

The PASCAL/R system is a single-user system. The system guaranties that no two users access a database in parallel.

Extensions to a multi-user system are under development.

6.2.2 Crash Recovery

The current version of PASCAL/R provides no restart and no recovery capabilities.

6.3 Operational Environment

6.3.1 Software Environment (Operating System)

The PASCAL/R system operates under the TOPS 10 operating system. It makes use of the file system in the same way standard PASCAL does, with the addition of direct block access.

Index structures are part of the Relational Access System (RAS, see 5.1).

The PASCAL/R system (Compiler, RSS, RAS, Utilities) is coded in PASCAL, except about one page of MACRO10 assembler code.

Portability problems are caused mainly by the PASCAL/R compiler; it is a one-pass compiler and the code generation is scattered all over the compilation process. However, the portation effort is reduced significantly if a PASCAL compiler exists on the target machine.

6.3.2 Hardware Environment (CPU, Memory, Peripherals)

```
CPU         : KA, KI, or KL processors
Main Memory : for compilation:
                           32 K words  for code
                                       (1 word = 36 bit)
                     + min. 13 K words  for data.
                  typically 45 K words.
```

```
for execution:
     ca. 7..15 K words  system code
     + min.  1 K words  program code
     + min.  1 K words  for data
     + min. 2x128 words  buffer size
```

Peripherals : discs

7. Essentially Relational Solutions For Generalized

In the PASCAL/R Project particular emphasis has been put on the following two issues :

1. design of a linguistic form (i.e. language) that fully supports the relational model as originally defined by Codd. Additionally language design goals are :

   - economy of concepts,

   - orthogonality,

   - generality.

   The syntax and semantics of the language are defined informally and formally (PASCAL/R Report and PASCAL/R Denotational Semantics Definition, see section 1.7).

   A particular goal of the language design effort was to study interfaces between programming languages and database models, and between compilers and database systems.

2. data independence and system optimization. The logical and physical definition of data is strictly separated. Thus, only the system (RSS and RAS, see section 5.1) can access and utilize information about the physical properties of data, e.g. quantity, access paths, storage structure. Within the PASCAL/R Project there is a strong tendency to use a subset of PASCAL/R to implement the language's full relational functionality.

8. Database Applications Using The System

Currently, PASCAL/R is used for

- Database Research:
  Principles of Database and Transaction Design;
  Maryland, Hamburg, Zuerich, Toronto.

- Implementation of Database Systems and Languages:
  Hamburg, Toronto.

- Teaching of Database Concepts:
  Hamburg, Zuerich.

- Database Development and Use:
  Hamburg.

The biggest PASCAL/R database developed at Hamburg University holds oceanographic data and biological and survey data on antarctic fish (Krilldb). Krilldb is under development since about 18 months and ran through three iterations; currently, it holds approximately 60 Mbyte of (primary) data in 50 relations and has been used by some 35 fish biologists. The procedure library for Krilldb has about 8000 PASCAL/R statements. Krilldb is used to store and evaluate data collected by the "First International Biomass Expedition" (FIBEX). Data collected by previous expeditions were kept and evaluated separately by means of file systems. Data conversion turns out to be a minor problem: small PASCAL/R programs read data from files of various formats, test the data on plausibility and integrity, and insert it into Krilldb.

Feature Analysis of the Peterlee Relational Test Vehicle*

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CONTENTS

1.0 INTRODUCTION

1.1 IDENTIFICATION

The Peterlee Relational Test Vehicle (PRTV) was developed at the IBM UK Scientific Centre in Peterlee, County Durham, England.

1.2 STATUS

1.2.1 SYSTEM

PRTV was a research system with the objectives of being a test bed for relational ideas, providing a suitable database subsystem for other projects and as a framework for performing database experiments. The project has been concluded and PRTV is no longer active.

1.2.2 APPLICATIONS

PRTV was designed to be a query oriented database subsystem. The accessing language, ISBL (Information System Base Language), was intended as a language that a more user friendly front end would compile into, although in some applications it was used directly.

Five applications of PRTV have been documented mostly involving queries against databases that remained fairly static in content. Databases of 110 Megabytes and relations containing 11-1/2 million tuples were handled satisfactorily. The final evaluation of PRTV (14), found that real world queries often ran into many hundreds of relational statements. The end users were not capable of writing such programs, instead they accessed the system through a parameter driven programs which invoked the PRTV system. Writing these programs was eased by a macro processor and a flexible way of defining extensions to the system.

1.3 SYSTEM BACKGROUND

Four distinct systems were developed in the period 1970-1978. IS/1.0 was operational by the end of 1971. It implemented the basic relational algebra but was found deficient in its end user language features and its overall performance. IS/1.1 improved the language features through the use of a macro processor, MP/3. In 1973/74, the performance issues were addressed by IS/1.2 adopting a new architecture and end user language. IS/1.2 was renamed PRTV in 1975 following the incorporation of facilities for end user extensions.

Use of the prototype in live applications was a major aspect of the research activity.

1.4 OVERALL PHILOSOPHY

PRTV did not attempt to provide the full requirements of an integrated database management system. Limited resources and work being done elsewhere directed the projects activities towards interactive query and problem solving applications. It was intended that PRTV be appropriate as:

* a stand alone query/problem solving system
* a database component of a specialized application
* a relational front end to a conventional database management system.

The need to extend easily the functions provided by the system was stressed throughout.

1.5 ESSENTIALLY RELATIONAL CHARACTERISTICS

PRTV does not support the insert, update and delete rules of Codd 1979, but has all the other characteristics of a relational system. It does not support semantic integrity constraints.

1.6 INTERFACES

1. Database Schema Definition: not implemented directly

2. Query Language: ISBL

3. Database Altering: ISBL

4. Constraint Definition: ISBL

5. Database Generation and Regeneration: utilities

6. Data schema redefinition and re-naming: not implemented

7. Report generation: not implemented

8. Data Entry: utility, or user written function

9. Security Definition, Monitoring and Control: ISBL used to define logon password and the relations seen by other users.

10. Database Control (utilities): no special language

11. Definition of Storage Structure, Indexes and Access Paths: no user interface

12. Database Dictionary: ISBL can be used to give properties of relations in the database

13. Interface to Programming Language: ISBL can be passed to PRTV from PL/I. Results are returned in relational files accessible to PL/I. Likewise relational files can be created in PL/I and passed to PRTV where they are turned into relations and stored.

    User extensions to PRTV are written to a certain protocol using PL/I.

1.7 DOCUMENTATION

1. P.A.V. Hall, P. Hitchcock and S.J.P. Todd, An Algebra of Relations for Machine Computation, Conference Record of the second ACM symposium on Principles of Programming Languages, Palo Alto, Calif., January 1975.

2. A. Hansel, A Formal Definition of a Relational Database System, IBM UK Scientific Centre Report No. 80, 1976.

3. S. Mandil, The MP/3 Macroprocessor, IBM UK Scientific Centre Report No. 44, 1973.

4. P. Hall, Optimisation of a Single Expression in a Relational Database System, IBM Journal of Research and Development, 20 3, 1976, 244-257.

5. S. Todd, Relational Database Research at the IBM UK Scientific Centre. Peterlee: A Survey, IBM UK Scientific Centre Report No. 93, 1977.

6. B. Aldred, S. Huyshe, A. Storey, Information Systems for Agricultural Crop Research, IBM UK Scientific Centre Report No. 103, December 1978.

7. B. Aldred, B. Smedley, UMS Technical Overview, IBM UK Scientific Centre Report No. 50, May 1974.

8. Swedish Environment Protection Board and IBM Sweden, An Experiment using Database Techniques in Environment Research, IBM Sweden, November 1972.

9. B.K. Aldred, B. Smedley, An Urban Management System - A General Overview, IBM UK Scientific Centre Report No. 81, 1976.

10. R.N. Stamper, The LEGOL Project, a Survey, IBM UK Scientific Centre Report No 81, 1976.

11. O. Bertrand, NLS, A Generator and Interpreter of User Languages, Proc. of IBM International Conference on Relational Database, Bari 1976.

12. M. Tibuya, Practice of Noun Phrase Model, Proc. of IBM International Conference on Relational Database, Bari 1976.

13. R.A. Storey, M. Bunzel, N. Ourusoff, W. Trebeljahr, Report of the World Health Organisation Information Systems Programme and IBM UK Scientific Centre Study on the Design of Information Systems, IBM UK Scientific Centre Report No. 105, January 1979.

14. R.A. Storey, An Evaluation of the Peterlee Relational Test Vehicle, IBM UK Scientific Centre Report No. 106., August 1979.

15. PRTV User Manual, IBM UK Scientific Centre Technical Note, No. 34.

16. S. Todd, The Peterlee Relational Test Vehicle - A System Overview, IBM Systems Journal, 15 4, 1976.

17. A. Storey, World Health Organisation/ IBM UK Scientific Centre Joint Study Report on the Design of Information Systems, IBM UK Scientific Centre Report No. 105, January 1979.

18. C. Jardine, J. Owlett, Applying a Relational Database System to Historical Data, IBM UK Technical Note No. 74, 1979.

19. P. Hitchcock, User Extensions to the Peterlee Relational Test Vehicle, Proceedings of the Conference on Very Large Data Bases II, Brussels, September 1976, North Holland 1976.

20. M.G. Notley, On the Design of a Graphic Display Language for Interrogating a Large Data Base, UKSC 4, June 1971.

21. M.G. Notley, Extensibility in Information Systems, Symposium on Extensible Languages, Grenoble, September 1971.

22. M.G. Notley, A Model of Extensible Language Systems, UKSC 22, March 1972.

23. M.G. Notley, The Peterlee IS/1 System, UKSC 18, March 1972.

24. J. Owlett, Deferring and Defining in Databases, Architecture and Models in Data Base Management Systems (ed. G.M. Nijssen), North Holland 1977.

25. R.A. Storey and S.J.P. Todd, Performance Analysis of Large Systems, Software Practice and Experience, vol. 7, no. 3,pp. 363-369, June 1977.

26. S.J.P. Todd, Implementation of the Join Operator in Relational Data Bases, IEE/IERE Colloquium on Information Structure and Storage Organisation, London, April 1974.

27. J.S.M. Verhofstad, The PRTV Optimizer: the Current State, TN 41, UKSC 83, May 1976.

28. J.S.M. Verhofstad, An Evaluation of the PRTV Optimiser, UKSC 91, in preparation.

29. IBM Corporation, IBM Interactive Management and Planning System under IMS/VS - User Guide, SB11-5220, December 1978.

2.0 DATABASE CONSTITUENTS

2.1 GENERAL DESCRIPTION

Term Translation Table

PRTV Term	Feature Catalogue Term
database	database
workspace	-
relation	relation
tuple	tuple
selector name	attribute name
component	attribute value
domain	domain

2.1.1 RELATIONAL VIEW

The constituents of a user′s view of a PRTV database are: DB (= database), WS (= workspace), R (= relation), T (= tuple), S (= selector = attribute = rolename), C (= component = object), D (= domain).

These constituents are related as follows:

A relational DB consists of R′s of possibly different types. A WS consists of R′s of possibly different type. An R consists of a set of T′s of identical type. A T is a set of S, C pairs with each C taken from a named domain D whose underlying type is character or numeric. The type of a relation or tuple is a set of S:D pairs.

2.1.2 RELATIONAL FILE VIEW

The constituents of the view of PRTV seen from a PL/I program are those of the relational view except that a relation is presented and accepted as a relational file (= RF). An RF is an ordered stream of T′s.

T′s do not appear directly as PL/I structures, rather the individual objects in a tuple are read by giving the appropriate selector name. An implicit cursor is used to

step through a relational file using a get next command.

When a relational file is written it could contain duplicate T´s. These duplicates are removed when the file is closed, converted to a relation and stored in the WS or DB.

2.2 DATABASE

2.2.1 DATABASE STRUCTURE

A database is a set of named relations. These names are partitioned into sets, not necessarily disjoint, which represent those relations that can be seen by each user of the database system. The database has no further structure from the point of view of PRTV.

2.2.2 DATABASE OPERATIONS

Database operations are part of ISBL. The commands are:

1. Create relation <rname>: adds an identifier to the set of relations.

2. Destroy relation <rname>: removes an identifier from the set.

3. Put <rname>: copies a relation from WS to the DB relation. Any relation may be copied to WS provided that a DB relation with the right name exists.

4. Get <rname>: copies a relation from DB to WS and enters its name in the WS.

5. Keep <rname>: When an assignment is made to a relation, the result is not realised immediately but is kept in the form of a definition. The PUT command would copy this definition into the database. The KEEP command evaluates the definition and stores the result in the database. This is intended as an optimization feature to avoid multiple evaluations of a common expression. The user would see a difference only if the assignment involved values which referred to a relation by name, rather than by value.

6. Pass relation <rname><user name><status>: gives another user the right to access a relation.

2.2.3 DATABASE CONSTRAINTS

No mechanism is implemented.

2.3 RELATION

2.3.1 RELATION STRUCTURE

A relation is a set of tuples. The order of the tuples is arbitrary, as is the order of the components of a tuple. There are no duplicate tuples in a relation.

The type of a relation is a set of S, D pairs. All the S names of a relation must be distinct, although the D names need not be.

Base relations have their type defined when they are entered into the DB or WS. Relations, which appear on the left-hand side of an assignment statement, inherit their type from that of the relational expression on the right-hand side. DB relations when created by Create Relation have a name but no type. This type is inherited from the corresponding WS relation when the Put Relation command is executed. It was felt that this interpretive style, cf APL, was better suited to the query environment.

2.3.2 RELATION OPERATIONS

ISBL has the six operations of the relational algebra i.e. selection, projection, union, intersection, difference and join. Additional operations are the renaming of selectors, the calculation and concatenation of a new component to each tuple in a relation, and glumping (or grouping). The division operator is not implemented. The result of any operation is itself a relation and so complex expressions can be built up without restriction. The compatibility requirements of the operands will be discussed with each operator.

2.3.3 RELATION CONSTRAINTS.

Not implemented.

2.3.4 ADDITIONAL PROPERTIES OF RELATIONS

None.

2.4 VIEWS

2.4.1 VIEW STRUCTURE

Views in PRTV are implemented in terms of relations which may be passed to other users. Their value is given by a relational expression. These views are essentially read only, in that there is no general mechanism which will reflect updates back to the underlying relations in whose terms the view is defined. Views can be defined and passed at any time.

2.4.2 VIEW OPERATIONS

Views are defined as relational expressions using the relational operations defined earlier. Names in the expressions may be bound in two ways, by value, or by name.

Binding by value is the default binding, the current value of the named relation is found and inserted in the expression. Any subsequent changes to the original relation are not reflected in the value of the view.

If binding by name is specified, the named relation is not evaluated at the time of definition of the view, but is evaluated every time the value of the view is used. If the underlying relation is changed in value, then these changes are seen in the view.

There are no restrictions on the use of views. If they are updated, this is seen as a redefinition of the relation which held the view, rather than a change to the underlying relations in whose terms the view was defined.

Views behave exactly as other relations and so may be stored in the database using the PUT operator and retrieved using the GET operation. In the case of a view defined in terms of relations bound by name, the view is not materialized, rather the view definition is stored. Views are only materialized when the value of the relation is required. See however the later section on optimization. Care is needed to

ensure that the base relations referred to in such stored views do not have their type changed, or are not deleted.

2.4.3 VIEW CONSTRAINTS

None.

2.4.4 ADDITIONAL PROPERTIES OF VIEWS

None.

2.5 TUPLE

2.5.1 TUPLE STRUCTURE

A tuple is specified in ISBL as a set of selector : domain : object triples. The ordering of objects within a tuple is immaterial. Selector names must be unique within a tuple. ISBL then treats the tuple constant as a relation containing one tuple; it can then be used by the relational operations in a natural fashion.

2.5.2 TUPLE OPERATIONS

None.

2.5.3 TUPLE CONSTRAINTS

Object values must agree with the data type of the domain.

2.5.4 ADDITIONAL PROPERTIES OF TUPLES.

Tuples are also presented to the user via the relational file interface.

2.6 ATTRIBUTES

2.6.1 ATTRIBUTE STRUCTURE

Attribute name is the feature analysis term for the selector names of PRTV.

Selector names distinguish the individual ´columns´ of a relation. The selector names of a relation can be changed by the project operator. They must be unique within a relation.

Within a tuple the selector identifies an object which takes its value from a named domain.

2.6.2 ATTRIBUTE OPERATIONS

The objects in a tuple which are selected by selectors can be combined into expressions, called selector expressions, according to the basic underlying datatype of the domain. The basic arithmetic operations are: +, -, *, / and POWER(N1,N2). The character operations have names similar to PL/I. They are: SUBSTR(S1,S2,S3), CONCAT(S1,S2), INDEX(S1,S2), VERIFY(S1,S2) and LENGTH(S). STREQU(S1,S2) compares two strings for equality when they are formed as the result of expressions.

It was a design feature of PRTV that it should be easy to add new functions should they be required.

Objects selected can also be compared if they come from the same domain. The comparison operations are =, ^=, >, >=, <, <=. Only = and ^= are applicable to character domains.

The use of selector expressions will be found under the individual relation operations.

2.6.3 ATTRIBUTE CONSTRAINTS

None.

2.6.4 ADDITIONAL PROPERTIES OF ATTRIBUTES

None.

2.7 DOMAIN

2.7.1 DOMAIN STRUCTURE

A domain is a set of possible values whose underlying datatype is numeric or character. Domains cannot be defined so that this set of possible values is restricted in some way. Domains are used to provide some compatibility checking for the relational operations.

2.7.2 DOMAIN OPERATIONS

The usual character and arithmetic operations are applicable, via selector expressions, to domains of the appropriate type.

2.7.3 DOMAIN CONSTRAINTS

None.

2.7.4 ADDITIONAL PROPERTIES OF DOMAINS

None.

2.8 ADDITIONAL DATABASE CONSTITUENTS

2.8.1 WORKSPACE

The intent of the WS is that relations can be manipulated and changed without affecting the database. WS operations are part of ISBL. Get and Put transfer relations to and from the workspace and database. The assignment statement of ISBL creates and gives values and types to new relations in

the workspace.

2.8.2 RELATIONAL FILES

An alternative view of a relation as a flat file is possible when the database is accessed via a PL/I program. See section 2.1.2

3.0 FUNCTIONAL CAPABILITIES

3.1 QUALIFICATION

3.1.1 RESTRICTION

Selection (:) acts on a relation and results in a new relation of the same type. This new relation is a subset of the old, each of its tuples satisfying some criteria called a <u>filter</u>. Filters contain comparisons between the objects in a tuple or between the objects and constants. The results of the comparisons, which can involve selector expressions, can be combined with the usual Boolean operators, |, ^, &, or (,).

Comparison is only allowed between objects from the same domain.

Example:

    S1: (SNAME = 'SMITH'|STATUS = 20)

Projection (%) acts on one relation to produce another. For each tuple in the original, the result contains a tuple with the selectors renamed, or only some objects present. A <u>projection list</u> specifies selection of components and their new names. It contains selector names from the input relation, each optionally qualified by a new name for the corresponding component in the result relation. This qualification is done using the <u>rename</u> (->) operator. To rename some components and to leave the remainder unchanged, a list is given of the selectors to be changed with their new names, followed by ,... (meaning and so on).

Example:

S% CITY -> TOWN, COLOR   yields the relation

TOWN	COLOR
London	Red
Paris	Green
Rome	Blue

SP% QTY -> AMOUNT,... yields a relation having type (S#,P#,AMOUNT).

Only selector names are changed by the rename operator. The domains remain unchanged.

Any duplicate tuples in the resulting relation are purged.

It is an error if the selector names in the relation are no longer distinct.

3.1.2 QUANTIFICATION

PRTV is not calculus oriented, and so the existential and universal quantifiers do not appear explicitly. However such queries can be answered in the algebra based systems and the glumping operator is useful in this regard.

3.1.3 SET OPERATIONS

Union (+) operates on two relations to produce a relation which is the set union of the two. The types of the two relations must be the same, and this is the type of the result relation. Any duplicate tuples are purged.

Intersection (.) produces the intersection of two relations of the same type.

Difference (-) has been generalised to work on two relations which may be of <u>different</u> types, but which have some selector; domain pairs in common. The result is a set of tuples in the first relation for which there are no tuples in the second relation which have equal values on the common components. If the types of the two input relations is the same, then we have the conventional set difference. The type of the result is the type of the first relation.

Example:

Those parts not currently supplied is given by the expression

P - SP.

which has type (P#, PNAME, COLOR, WEIGHT, CITY).

3.1.4 JOIN

Join has been generalised in the same way as difference.

The join operator (*) accepts two operand relations to produce a new relation. The type of the join is dictated by the selector names that each relation has in common. At one extreme, if there are no selector names in common, then every tuple in the first relation is paired with every typle in the second. Each pair is concatenated to give a tuple in the result relation. This is the full quadratic join or cross product.

If some selector names match, tuples are put into the result relation only if the values for the common selectors in each of the contributing tuples also match. This is a join on common selectors or an equi-join over several domains.

If the two relations have the same type, then join degenerates into an intersection.

Example:

A = (S*P)%S#,P# is an equijoin on CITY, and gives potential local suppliers of parts.

The expression, SP - A, gives information about things which are not supplied locally.

The <u>rename</u> extension to the project operator was introduced so that the right type of join could be described.

An example of this would be a reflexive join.

Consider the relation PP:(super:part,sub:part). It has selector names ´super´ and ´sub´ which serve to describe the relationship between a part and the parts that make it up. To expand the parts explosion by one level, we must join the relation to itself This is achieved by taking the ´sub´ selector of the first relation and the ´super´ selector of the second relation and renaming them to the selector ´link´. The join will now take place over this common

selector name resulting in a relation with selectors 'super', 'link' and 'sub'. The ISBL expression follows:

(PP % super,sub->link) * (PP % sub,super->link)

3.1.5 NESTING AND CLOSURE

The result of any relational operation in PRTV is itself a relation. Complete nesting of relational expressions is allowed.

3.1.6 ADDITIONAL ASPECTS OF QUALIFICATION.

None.

3.2 RETRIEVAL AND PRESENTATION

3.2.1 DATABASE QUERIES

Database queries are expressed as relational expressions. The result of a query is a relation which may be stored or listed. The query facility is relationally complete in the sense of DSL Alpha.

The design of PRTV made it easy to add user defined functions to the query language.

3.2.2 RETRIEVAL OF INFORMATION ABOUT DATABASE CONSTITUENTS

PRTV contains the following expressions which give information about the results of relational expressions. This information is returned as a relation, and so can subsequently be used in queries.

DEGREE (expression) - gives the degree, (no. of selectors), of the relational expression.

CARD (expression) - gives the cardinality of the relational expression.

DOMAINS (expression) - gives the domain names and selector names of the specified expression.

PRTV also contains the commands:

LIST RELATIONS - gives the relations accessible to this user, together with their domain and selector names.

LIST DOMAINS - gives the domain names known to this user with their underlying data type of character or number.

LIST USERS - gives the logon identifiers of all the authorized usersof this particular database.

3.2.3 RETRIEVAL OF SYSTEM PERFORMANCE DATA

None beyond that supplied by querying the operating system.

3.2.4 REPORT GENERATION

Not implemented as part of PRTV. The intent was that this would be supplied via the PL/I interface.

3.2.5 CONSTRAINTS AND LIMITATION.

No limitation.

3.2.6 ADDITIONAL ASPECTS OF RETRIEVAL AND PRESENTATION

A PL/I program accesses a relation as a relational file. Any ISBL command can also be issued from a PL/I program. There are also PL/I procedures to obtain information about database constituents.

3.3 ALTERATION

Relations in the workspace may have their values changed by the assignment of a relational expression. PRTV adopts an APL-like approach to this assignment. The relation on the

left hand side takes it type from the type of the expression on the right hand side. This type is always well defined. This means that the type of a relation may be change by assignment. New selectors could be added, or the type changed completely.

New relations in the workspace may be created by assignment by virtue of their appearance on the left hand side of an assignment statement.

Relations in the database have their value changed by using the PUT operation to replace the old value with the corresponding one from the workspace.

3.3.1 INSERT FACILITIES

For relations a change relation is built up and the union operator used. A change relation may be built from tuple constants or from a user defined function. To change the database structure Create Relation, Create Domain are used.

3.3.2 DELETE FACILITIES:

Similar to insert, except that set difference is used. To change the database structure, Destroy Relation, Destroy Domain, and Drop may be used.

No constraints are implemented. This is dangerous because of defined relations.

3.3.3 MODIFY FACILITIES.

Usually performed as a combination of insert and delete operations.

3.3.4 COMMIT AND UNDO FACILITIES

PRTV supports the idea of a workspace. Relations may have their values changed in the workspace. These changes can subsequently be committed to the permanent database.

3.3.5 ADDITIONAL ALTERATION FACILITIES

Concatenation operator.

The concatenation operator (#) allows the concatenation of new objects to a tuple. The value of this object is defined in terms of the existing objects in the tuple by the means of Selector expressions. The selector name and domain name of the new object must be defined.

Example: Abbreviate part names to three characters

A = P#ABBREV(PNAME) <- SUBSTR(PNAME,1,3)

P = A%(P#,ABBREV -> PNAME,COLOR,WEIGHT,CITY).

3.4 ADDITIONAL FUNCTIONAL CAPABILITIES

3.4.1 ARITHMETIC AND STRING OPERATIONS

See selector expressions

3.4.2 SORTING

Because of the way PRTV is implemented, relations are presented so that they are ordered on the first domain and within the first, on the second etc. This is not guaranteed as part of the data model. The order of domains can be changed by the projection operator.

3.4.3 LIBRARY FUNCTIONS

There are some builtin functions such as SUBSTR, INDEX which are used in selector expressions. The builtin function SUM is used in association with the glumping operator to formulate the functions of COUNT, TOTAL, AVERAGE etc. PRTV was designed in such a way that it is very easy to include and use user defined functions, making a special library of builtin functions unnecessary.

3.4.4 USER DEFINED FUNCTIONS

Tuple at a time extensions can be defined through selector expressions. Library functions are added by writing a PL/I procedure to a certain protocol and relinking the system.

Full user defined functions are defined using the relational file interface and the CALL statement.

3.4.5 TRANSACTIONS

Not implemented.

3.4.6 MULTI-TUPLE ALTERATIONS

Nothing special was implemented.

3.4.7 GROUPING

PRTV implements the glumping operation. This is a class of queries which have the following general structure.

1. First partition the set of tuples into groups.
2. Act on each group to produce one (or zero) tuples which form a new relation.

The ISBL takes the form

    Relational expression $(control fields)(selector(domain)
    <- outer selector expression...)

where $ represents the glumping operator, control fields represent those fields on which grouping is defined, and the outer selector expression represents a constant, SUM (inner expression), or any selector expression. An inner expression may be a constant or a field which is not a control field.

Example:

Find the average weight of parts from each city.

```
    P $(CITY)(TOTAL PARTS(N) <- SUM(1)
              TOTAL WEIGHT(N) <- SUM(WEIGHT)
              AVG WEIGHT(N) <- TOTAL WEIGHT/TOTAL PARTS.)
```

The result is a relation with selectors

CITY, TOTAL PARTS, TOTAL WEIGHT, AVG WEIGHT.

3.4.8 EXCEPTION HANDLING MECHANSISMS

Nothing special was implemented.

3.4.9 ADDITIONAL FUNCTIONAL CAPABILITIES

None.

4.0 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES.

These are not separated from the language which has already been described and which is available to all users. The way that it should be used in practice is the following. Starting with an empty database a special user, the database administrator, is created. He creates and loads the appropriate relations, creates additional users, and passes relations or views of relations to them.

There are system utilities to reorganize the database.

5.0 INTERFACES AND DBMS ARCHITECTURE

5.1 SYSTEM ARCHITECTURE

PRTV was designed as a database subsystem. It is accessed through the language ISBL either directly by the user at a terminal, or through the relational file interface from the host language PL/I.

5.2 INTERFACE DESCRIPTIONS

5.2.1 ISBL

This language is the data sublanguage used directly by an end user, compiled into by a particular user front end, or called from a PL/I program. The language is a linear text stream. It is used to access all the constituents named earlier. ISBL is based on the relational algebra. Relations are manipulated as sets, but the results are presented as tables. User extensions, which are written in PL/I can be invoked by a CALL statement or by their use in selector expressions.

5.2.2 INTERFACE FROM PL/I

ISBL statements can be passed to PRTV by using a PL/I call statement. The results are passed back to PL/I through the relational file interface.

6.0 OPERATIONAL ASPECTS

6.1 SECURITY

6.1.1 ACCESS CONTROL

Simple password protection at logon time. No logging or audit trails. Each user sees his own set of relations, some of which may be views of relations held by others.

6.2 PHYSICAL INTEGRITY

6.2.1 CONCURRENCY CONTROL

No concurrent access.

6.2.2 CRASH RECOVERY

Not implemented.

6.3 OPERATING ENVIRONMENT

6.3.1 SOFTWARE ENVIRONMENT

PRTV runs under CMS or TSO, and uses the basic file access methods.

6.3.2 HARDWARE ENVIRONMENT

PRTV was implemented on IBM 370/145 and requires a 1 Megabyte virtual machine under CMS or an 896K byte virtual

partition under OS.

PRTV consists of about 17,000 lines of PL/I and 4,000 lines of Basic Assembler Language. The executable module occupies about 400K bytes.

7.0 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS

7.1 GLUMPING OR GROUPING

Although it is possible to specify any operation on relations using the tuple at a time interface into PL/I, there is an important class of extensions which can be considered separately within the relational framework. These have the general structure: first partition the set of tuples into groups, and then act on each of the groups to produce one (or zero) tuples which form a new relation. This corresponds to producing relations which are not in first normal form, (elements of tuples can themselves be a set of tuples or a relation), and then acting on each of these sub-relations. The PRTV designers decided that the user should not be allowed to store and manipulate relations which were not in first normal form and so the partitioning and the corresponding actions were coalesced together into one glumping operation. The primitive builtin function SUM, allows for the definition of the more general operations such as SUBTOTAL etc. in a more general way. This approach does not extend to grouping hierarchies of more than two levels, nor does it allow glumped relations to be loaded or displayed, both of which might be useful presentations for end users. For an example of glumping see the earlier section on grouping

7.2 SELECTOR RENAMING

The problem addressed here is the one of closure. The result of any relational expression is itself an expression whose type must be known. It was felt that the conventional algebraic join definitions that were known in 1974 did not make the type of the result sufficiently clear if the domains being joined had different selector names. Often this was resolved by assignment to a relation of a known type or by a reliance on column ordering. Both these techniques were thought to be unsatisfactory and the definition of join based on common names was implemented. This forced the designers to implement a renaming operation, which was found to be quite usable in practice.

7.3 OPTIMIZATION

The use of relations and their set oriented operations meant that sophisticated solutions could be found to the database optimization problem. The underlying implementation technique used was to delay the evaluation of a relation or a relational expression until that result was needed. This is the case if the result is to be listed, turned into a relational file or stored in the database using the KEEP operation. Instead a table is built up which associates each relation name with the expression which is to be evaluated to find its value. These are expressions are not exactly the same as the original, some compilation has been done to resolve names where necessary, a syntax check has been done etc. When the relation is subsequently referred to, this expression is used to build up a more complex expression for the result. This deferred evaluation of intermediate results continues until the expression must be evaluated. Optimization techniques can then be used to change the order of evaluation, to recognize common sub-expressions etc. More detail can be found in (4,27,28). When evaluation does take place it happens in a stream fashion. Tuples are requested one at a time from the top of the evaluation tree. These requests filter down to the base relations at the bottom, where they are recovered from the database again a tuple at a time. This means that a wrong result could be rejected by a user before the complete relation has been realised. In practice, this idealised evaluation is not always possible, it may be necessasry to have a break point in the evaluation tree so that the intermediate result can be sorted. The optimization techniques try to delay this as long as possible so that the size of the set to be sorted is as small as possible.

It is interesting to note that this idea of deferred realisation has very little effect on the user language. The only place where it is exposed is the necessity for the KEEP operation which forces realisation of an expression before it is stored in the database. Deferred realisation and the mechanism for views are clearly very similar.

The large scale evaluation of PRTV (14) found that, although in theory the user is not aware of optimization, performance considerations meant that he should have some notion of what was going on.

8.0 DATABASE APPLICATIONS USING THE SYSTEM

PRTV was developed as an experimental tool to investigate relational techniques. It has now been evaluated (13,14) and is no longer in use.

There are six major applications of PRTV in the public domain.

The first was a joint project in 1972 between the Swedish Environmental Protection Board and IBM Sweden, studying the effect of thermal pollution by nuclear power stations using the Baltic Sea for cooling water (8).

The second was a joint project with the Greater London Council in urban planning and used an early version of PRTV as a database subsystem. It made use of the extnsibility features to enhance calculation and report generation facilities and in particular introduced facilities for the processing of geographic data. The database size was approximately 60 Megabytes (9).

The third application, LEGOL (10), provided a formal framework for describing statute law, PRTV being used to store both the legal rules and precedents. A partricular characteristic of the LEGOL application was that a large number of relational operations (e.g. 60) were carried out on small data volumes (e.g. relations with 10 tuples). PRTV was principally designed to carry out fewer operations on substantially larger relations.

In the fourth application (11,12), PRTV was used in natural language and user oriented query systems, where the main research was directed towards problems of language interpretation.

The fifth application was a major evaluation of PRTV, conducted as a joint project with the World Health Organization (WHO), (13,14). The database was large, 108 Megabytes, with one relation containing 11-1/2 million tuples. To improve performance, this relation was reduced to 500,000 tuples by storing some fields as repeating groups. Some of the queries required of the order of 100 ISBL statements for their solutions. To make the system more accessible to the end users, a parametric interface was written for certain classes of query. The flexibility of the architecture made this and other links to support functions such as report generation and complex statistical analysis very easy.

Functionally, the system covered most of the applications which were running on the previous COBOL based system and indeed, the scope of the application was broadened because of the extensibility inherent in PRTV. Many queries were answered which could not have been answered by the existing system.

The major difficulties were performance related arising from the volumes of data. Some of these problems had been addressed in the optimizer component of PRTV, but in practice, it was not possible to shield the end user entirely from such things as the best sequence for operations, etc.

Finally, IBM has announced an International Field Program called Interactive Management Planning System or IMPS (29). IMPS is a relational system which aslo allows a read only view of IMS data.The external syntax of IMPS is not the same as that of PRTV, although the function is very similar. The underlying relational access methods upon which it is built are those of PRTV.

Feature Catalogue of Query-By-Example

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QBE 1

Feature Catalog of Query-By-Example
(December 1980)
by
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(Version 2)

(This is a preliminary document subject to change. It does not constitute a representation of Query-By-Example by the IBM Corporation)

1.0 Introduction

1.1 Identification

QUERY-BY-EXAMPLE. The system was introduced by the IBM Corporation as an Installed User Program (IUP) in September 1978. QUERY-BY-EXAMPLE was originally a research project at the T. J. Watson Research Lab in Yorktown, N. Y. The principal architect of the language is Dr. Moshe' Zloof, IBM Research, Yorktown.

1.2 Status

1.2.1 System

The system is currently an Installed User Program, a product of the IBM Corporation Data Processing Division. This description is restricted to the current IUP version of QBE. It is also being used as the nucleus of a research (experimental) project in office automation at Yorktown. The extended system is called Office procedures By Example (OBE) which involves not only tables but text, reports and charts as well as the ability to distribute these objects according to several criteria.

1.2.2 Applications

QBE can be used in support of a broad range of applications such as accounting, finance, inventory teaching, sales, oil and chemical analysis and personnel. It is useful as an application development tool as well as an interactive query processor. The system runs under VM-CMS. The maximum size database is 226 megabytes.

1.3 System Background

As noted in 1.1, the system was originally experimental. It underwent revisions and extensions before its release as a product; many of these were made as a result of human factors experimentation.

1.4 Overall Philosophy

Query-By-Example's outstanding characteristic is probably its usefulness to non-programmers and those with only limited programming skills. Users can create base relations, insert, delete and modify relations, create snapshots (derived static relations), and query against relations using a language as powerful as the relational calculus.

The user thinks in terms of tables, rows and columns and performs database operations by making appropriate entries in skeleton tables. The system provides a comprehensive range of authorization and security facilities. In addition, a programming interface is provided by which QBE can be called from PL/I or APL.

The philosophy behind Query-By-Example is to provide the end-user a powerful tool to define, query, update and control a relational database with the perception of manual manipulation of tables. This is achieved by programming directly on two-dimensional skeletons of tables thus using a metaphor familiar to the user as opposed to a linear string programming language, (although a linear syntax is also available). It is important to stress that users can define their own tables, thus setting up their own applications, without the aid of professional programmers. In general, the system seeks to facilitate user interface through a uniform table oriented language for major database processing functions.

1.5 Essentially Relational Characteristics

QBE processes relations represented as two-dimensional tables. There are no external links among tables that are perceptible to the user. There are no order dependencies among tuples or attributes; no <u>essential</u> insert, delete, update dependencies; and no index dependencies for data access.

Indeed, there is a real sense in which the relational data model has been captured and extended to the user interface insofar as query and database modification functions are expressed through the use of two-dimensional tables. Union, Intersection, Difference, Projection, and Join can be expressed in the language.
Insert, delete and update rules as specified in CODD's later work are not supported on a predeclared basis; but the query language can be used to specify referential integrity as a part of an update transaction. Specifically, query-dependent insert, delete and update statements can be used to enforce CODD's Rule 2.

1.6 Interfaces

Query-By-Example has two language forms: tabular (self-contained) and linear (program embedded). The first makes use of two-dimensional tables as the vehicle thru which the user (1) requests information from the database (2) specifies changes to tables (3) specifies changes to the database. The objectives

of this technique is to allow users to express various functions in tabular format, thus capitalizing on the tabular form of data organization which the system employs. Simply, since the user thinks of data as stored in tables, the system allows the user to express queries and other functions in the same way. The user specifies what information is desired by making entries in appropriate columns of relevant tables. An example illustrates this technique against a table, called PART.

Display (or print) the names of green parts.

PART	P#	PNAME	COLOR	WEIGHT	CITY
		P._ROD	GREEN		

The entries for the query show the two basic concepts involved in QBE query formulation (1) constant elements and (2) example elements. In this case GREEN is the constant element entered by the user under COLOR. _ROD is an example of a possible answer. Since the user wants to see elements of this sort, this example element is preceded by P., for print (or display). From the simple, basic notions of example element, constant element, and tables, extremely complex queries can be constructed. This language form is provide for interactive terminal users. It constitutes a self-contained language form.

A linear syntax is also provided for use with PL/I and APL. This one-dimensional syntax can be used to define tables as well as specify queries embedded in the two host languages mentioned. There are no known limitations to the expressive power of this format for query as compared to the tabular format. That is, any query that can be formulated in the two-dimensional screen format can be expressed in the linear format.

Find the names of green parts.

PART(PNAME/COLOR)
(/P._ROD/GREEN)

The linear representation of a query is entered within a PL/I application program or an APL workspace. QBE processes the query when invoked from the program or workspace. Linear queries can be stored in CMS files and executed via a CMS terminal session.

In both modes, queries can be stored for subsequent execution. Both linear and two-dimensional forms use a small set of keywords.

Interfaces for specific functions are as follows:

1. Database schema definition: QBE
2. Query: QBE
3. Alteration: QBE
4. Constraint definition: QBE
5. Database generation and regeneration: bulk loader, LQBEDB. IMS extract from a DL/I database.

6. Database schema redefinition and renaming: QBE
7. Report generation: the system provides images of multiple tables as output; table names and column names can be customized for output; column width for output is under user control through QBE.
8. Data entry: insertion via QBE or utilities as in 10 below.
9. Monitoring: the user who creates a table has complete control over its use.
10. Database control (utilities): bulk loader from any normalized file; IMS extract; dump (CMS facility used to record disk image) and interactive dump through QBE snapshots; backup through CMS utility (CMSDDR); restore through log. Recovery using normal CMS facilities.
11. Definition of storage structure: automatic system function; indices: user can request column inversions; access path selection: automatic system function.
12. Data dictionary: limited dictionary with entries retrievable through QBE.
13. Special purpose language: none.

1.7 Documentation

1. Zloof, M. M. (1977). "Query-by-Example: A Data Base Language". IBM Systems J., vol. 16, no. 4.

2. Zloof, M. M. (1975). "Query-by-Example". AFIPS Conf. Proc., National Computer Conf. 44, pp. 431-438.

3. Zloof, M. M. (Sept. 22-24, 1975). "Query-by-Example: The Invocation and Definition of Tables and Forms". Proc. of the Int'l. Conf. on Very Large Data Bases, Boston, Massachusetts, pp. 1-24.

4. Zloof, M. M. (1975). "Query-by-Example" Operations on the Transitive Closure". IBM Research Report RC 5526, IBM Thomas J. Watson Research Center, Yorktown Heights, New York.

5. Zloof, M. M. (1976). "Query-by-Example: Operation on Hierarchical Data Bases". AFIPS Conf. Proc., National Computer Conf. 45, pp. 845-853.

6. Zloof, M. M. (Feb. 7, 1978). "Security and Integrity Within the Query-by-Example Data Base Management Language". IBM Research Report RC 6982, IBM Thomas J. Watson Reearch Center, Yorktown Heights, New York.

7. Query-by-Example Terminal User's Guide, IBM Manual SH20-2078

8. Query-by-Example Program Description/Operations Manual, IBM Manual SH20-2077

9. Zloof, M. M. (1980). "A Language for Office and Business Automation", IBM Research Report RC 8091, Thomas J. Watson Research Center, Yorktown Heights, N.Y. (appears in Proceedings of NCC Office Automation 1980, March 3-5, 1980, Atlanta, Georgia).

2.0 Database Constituents

2.1 General Description

2.1.1 Term translation table

Feature Catalog Term	QBE Term
Database	Database
Relation	Table
View	Snapshot
Tuple	Row
Attribute	Column
Domain	Domain

In addition, a value of a specified attribute for a given table (i.e., the component of a row) is a DATA ELEMENT. The primary key of a relation is a table KEY.

2.2 Database

2.2.1 Database Structure

A database is a collection of tables defined by one or more users, or, by the DBA, and system tables as follows:

TABLE table
DOMAIN table
PROGRAM table
AUTHORITY table

The TABLE table contains the names of the tables in the database and the owner of each table. The DOMAIN table contains all previously defined domains with their names, ATTRIBUTES (QBE term for data characteristics such as data type, image, minimum and maximum input column width), and owners. The PROGRAM table contains the names of stored queries or programs. It contains query name, owner and descriptive comments. The AUTHORITY table contains table names and the identities of users authorized to access them on a selective basis i.e., access to: print, update, delete and insert.

At the schema level, a database consists simply of table names and column names for the collection of tables in the database associated with a user identification. That is, all tables a user is authorized to access. At the instance level, the database consists of all rows of all tables which a particular user is authorized to access.

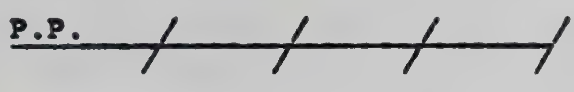
2.2.2 Database Operations

The only significant database operations are those used to display the names of tables and columns in the database.

The P. operator is used to obtain the names of all tables in the database. This operator is entered by the user in the left-most column of a skeleton table.

The system response is a display of all user-defined tables and system tables.

The P.P. yields all table and column names. It constitutes a user's DATA BASE DIRECTORY.



2.2.3 Database Contraints

Authority over user tables is controlled by the user who defines and creates the table. System tables are created and maintained by the system. Authority to see and update system table contents can be granted to users only by the DBA. The DBA has unlimited access to all user defined tables. Since preparation of external storage areas for all user defined tables can be accomplished only under the DBA identification, the DBA has ultimate authority over all table creation.

A database cannot exceed 226 megabytes.

2.3 Relation

2.3.1 Relation Structure

A relation, defined as a set of ordered n-tuples whose components consist of elements from n-domains (not necessarily distinct), is represented as a two-dimensional table of columns and rows. A table is the only perception of a relation which the user has. Duplicate tuples are not allowed; attribute order is insignificant.

2.3.2 Relation Operations

Important operations on relations are as follows:

1. I.table name I. - defines a table with the given table and column names i.e. insert the named table into the database directory of tables (TABLE table)

2. D.table name - deletes the named table from the database directory; all tuples of the named table must be deleted prior to this operation

3. table $name_1$ U. table $name_2$ - Changes the name of the table from table $name_1$, to table $name_2$

These operations are performed on displayed skeleton tables. Thus, to insert a new table name with related column names the user would key the I. operator and the table and column names into the skeleton table as follows:

I. SUPPLY I.	S#	SNAME	STATUS	CITY

4. P. - This operator displays or prints all rows of a table. To this end it is used as a row operator.

Display the entire SUPPLY table

SUPPLY	S#	SNAME	STATUS	CITY
P.				

The user keys in the 'P.' operator under the table name.

5. D. - deletes all rows of a table

   Delete all information about suppliers

SUPPLY	S#	SNAME	STATUS	CITY
D.				

6. I. column name - used to add a new column to the definition of a table already defined to the system.

SPJ	S#	P#	J#	I.QTY

7. D. column name - deletes a column from the definition of a table already defined to the system.

SPJ	S#	P#	D.J#	QTY

   Result:

SPJ	S#	P#	QTY

8. Describe - creates table and domain definitions needed by the bulk loader; used when saving a table for subsequent return to the database.

9. Disk - creates data elements and column definitions needed by the bulk loader; used when saving a table for subsequent return to the database. This command and DESCRIBE can only be used by the DBA.

10. I. table name I., P. - these operators can be used in conjunction to create a SNAPSHOT, i.e., a static derived view from one or more tables.

11. AUTH - used to specify authority over a user created table. This operator is used in conjunction with I. (grants authority), D. (withdraws authority) and U. (changes authority).

Grant authority to CODD to print SNAME and STATUS in the SUPPLY table.

```
        SUPPLY    / S#   / SNAME   / STATUS   / CITY/
I. AUTH(P.)CODD          _N        _M
```

2.3.3. Relation Constraints

Only authorized users of tables can delete, print/display, or create a snapshot of those tables.

Every table must have a KEY column to insure uniqueness of rows.

A column can be added to a table that contains data only by creating a SNAPSHOT of that table.

A table cannot have more than 100 columns.

Tables must be 1st normal form relations.

2.3.4.

Design considerations at the gross logical DB design level involve answers to the following questions:

1. What will the tables contain?
2. What makes each table unique?
3. What does the data in each column look like?
4. What columns will the user need to compare, either in the same or in different tables.

2.4 Views

The system supports static views, but does not support dynamic views. The system term for the former is SNAPSHOT. There is no difference in the structure of a SNAPSHOT and other tables.

Snapshots are created as user defined tables using the I. (insert) operator and the full facilities of the query language to define the new relation. The naming mechanism is the same as the mechanism used to create the source relations.

Keys are inherited from source relations, but users can override this automatic key propagation.

The following example indicates how snapshots are named and derived.

Create a SNAPSHOT of those suppliers who supply project J1.

```
SUPPLY  / S#  / SNAME  / STATUS  / CITY/    SPJ / S# / P# / J# / QTY/
        / _X  / _Y    /         /     /       / _X /    / J1/     /
```

```
I.SSUPP I / S#  / SNAME /
   I.    /  _X  /  _Y   /
```

SSUP is the SNAPSHOT consisting of rows of suppliers who satisfy the query.

2.4.2. View Operators

Any operation valid for base relations can be used on SNAPSHOTS.

2.4.3. View Constraints

Any user authorized to read a base relation can create a snapshot using that relation. Otherwise, no other constraints found.

2.4.4. Additional Properties of Views

SNAPSHOTS can be useful in creating and manipulating subsets of a base table as "private files". They are also useful in creating back-up copies of a table prior to modification of the table.

2.5 Tuple

2.5.1

A tuple is a row in a table. It consists of attributes defined over domains. A row is implicity defined when the table is defined. Tuples are also created dynamically as the results of queries. Keys are defined at the relation level. Unique tuple identification is achieved through a table KEY which consists of one or more column names (attributes).

2.5.2 Tuple Operations

Tuples may be inserted, deleted, updated or retrieved. New tuples can be formed from tuples or components of tuples in one or more tables. This formation of new tuples may be based on matching values of a common domain. Normally, redundant tuples are not retrieved, but the ALL. operator can be used to return duplicates when desired.

Query-dependent inserts, deletes and updates can be specified. For example, a tuple insertion can be dependent upon the outcome of a query.

Tuples are not ordered; order can be requested for display or other output. Tuples must be unique. The system rejects attempts to violate uniqueness and notifies the user by message.

2.5.4. Additional Properties of Tuples

Tuples are treated as elements of a set or rows in a table.

2.6 Attributes

An attribute is a COLUMN NAME. Attributes are defined based on domains (defined at data definition time). Multiple attributes can be defined over a single domain.

Attributes are defined as a part of table definition. After the table column names have been entered in the skeleton table (see section2.3.2), the system displays the following table:

SUPPLY	S#	SNAME	STATUS	CITY
KEY	Y(DEF)	Y(DEF)	Y(DEF)	Y(DEF)
DOMAIN	-	-	-	-
TYPE	-	-	-	-
IMAGE	-	-	-	-
ICW	2(DEF)	5(DEF)	6(DEF)	4(DEF)
OCW	-	-	-	-
POSITION	1	2	3	4
INVERSION	Y(DEF)	Y(DEF)	Y(DEF)	Y(DEF)

At this point, the system has assumed a default option of 'yes' for KEY in every column. Similar defaults are assumed for other data characteristics (system name is ATTRIBUTE). The user can accept the defaults or modify the table as appropriate, thus overriding the defaults. The meanings of the keywords provided in the left-most column is as follows:

- KEY - Yes or No
- DOMAIN - The user may reference a previously defined domain or create a new domain. The domain "definition" consists of domain name and TYPE, IMAGE, ICW and OCW as defined below. When a previously defined domain is referenced, these four characteristics are inherited.
- TYPE - Character, numeric (fixed or float), date, or time.
- IMAGE - Defines output image for all data except character. This is an edit (for display or print) that includes space for dollar sign, decimal point, plus or minus, credit symbol or exponent. Leading zeros can be replaced by blanks or asterisks. Date components can be defined, e.g., day, month, year, as well as time, e.g., hour, minute, second.
- ICW - Maximum number of characters or numbers that can be input to this column without widening the column.

OCW - Width of character data for output (display).
POSITION - The sequence of columns when the system produces column headings, that is, unless dynamically modified by the user.
INVERSION - Index created for the column. (Y or N)

Tuples can be manipulated with the standard comparison operators =, >, <, ¬=, >=, <=. Arithmetic operators are as follows

+ (Add), - (Subtract), *(Multiply),
/ (Divide), **(Raise to a power (A^2))

The following aggregation functions are available as built-in functions:

FUNCTION	MEANING
CNT.	Count the number of items.
SUM.	Add the items together; may be used only with numeric data.
AVG.	Find the average of the items; may be used only with numeric data.
MAX.	Find the maximum (largest) value.
MIN.	Find the minimum (smallest) value.
UNQ.	Use unique values only (omit duplicates).

The unique function can be used with the count, sum, or average functions. Thus, CNT.UNQ. means count only the unique values.

For all of these operations, data must be of the same type.

2.7 Domain

2.7.1 Domain Structure

A domain is defined as the set of values from which the values (system term is DATA ELEMENT) in an attribute (COLUMN) are drawn. Domain data types are:

Character
Fixed
Float
Date
Time

2.7.2 Domain Operations

Domain names, IMAGE, TYPE, OCW, ICW can be read from the DOMAIN table.

2.7.3 Domain Constraints

Domain values are variable length not exceeding 3200 bytes. Maximum column width for output is 75. Data which exceeds the maximum is folded automatically.

2.8 Additional Database Constituents

Transactions, Database Directory (system tables).

3.0 Functional Capabilities

3.1 Qualification

The basic framework within which retrieval (identification and selection) is achieved in QBE has already been presented in Section 1.7 of this report. The fundamental selection operators are:

P.	- selects a column or row for display or print.
example element	- provides an "example" of the data to be selected; can be used to link data in two or more tables i.e., as a linking example element.
constant	- qualifies selection to some subset of the rows in a table.

Example

Select all rows of the SUPPLY table.

SUPPLY	S#	SNAME	CITY	STATUS
P.				

Select all data elements (values) of the CITY column (attribute). (Projection)

SUPPLY	S#	SNAME	CITY	STATUS
			P._N.Y.	

3.1.1 Restriction

Restriction is performed through the use of example elements with the P. operator.

Example

Find all the rows which have suppliers in New York City.

SUPPLY	S#	SNAME	CITY	STATUS
P.			N.Y.	

(Projection has already been shown in 3.1.)

Restriction and projection can be combined as follows:

Print the part numbers and weights of red parts that are less than 10 lbs.

PART	P#	PNAME	COLOR	WEIGHT
	P._COG		RED	P. $<$10

Tuple attributes (columns) can be compared to other tuple attributes as well as to constants.

3.1.2 Quantification

Existential quantification is implicit in those operations that result in the selection of one or more rows of a table. It is also implicit in the use of a LINKING EXAMPLE ELEMENT.

Example

Find the supplier names for suppliers who supply Project J4.

SUPPLY	S#	SNAME	...
	X	P.	

SPJ	S#	P#	J#	QTY
	X		J4	

Universal quantification is supported indirectly through the use of the Count, CNT. operator.

3.1.3 Set Operations

Set operations are supported and can be expressed explicity as follows:

UNION:

SUPPLY	S#	SNAME
	_X1	_Y1

SSUPPLY	S#	SNAME
	_X2	_Y2

SS	S#	SNAME
	_X1	_Y1
P.	_X2	_Y2

(Where SS is a user output table)

INTERSECTION:

SUPPLY	S#	SNAME
	_X	_Y

SSUPPLY	S#	SNAME
	_X	_Y

SS	S#	SNAME
P.	_X	_Y

DIFFERENCE:

SUPPLY	S#	SNAME
	_X	_Y

SSUPPLY	S#	SNAME
¬	_X	_Y

SS	S#	SNAME
P.	_X	_Y

EXTENDED CARTESIAN PRODUCT:

SUPPLY	S#	SNAME
	_W	_X

SSUPPLY	S#	SNAME
	_Y	_Z

SS	S#	SNAME	SS#	SSNAME
P.	_W	_X	_Y	_Z

3.1.4 Joining

Joins are expressed by specifying the same LINKING

EXAMPLE ELEMENT in multiple tables.

Find the names of suppliers for the part with P#=P5.

```
SUPPLY /  S# / SNAME /            SP /  S# /  P# /
-------/-----/-------/            ---/-----/-----/
      / _X  / P.    /                /_X  /  P5 /
```

Result:

```
 / SNAME /
/-------/
```

(Result contains the names of suppliers for which the expression is true.)

A table can be joined to itself. Up to 12 tables can be joined in a single query. Equi-join, Hi-join, Lo-join and natural join are supported. Join columns must be of the same data TYPE.

3.1.5 Nesting and Closure

Queries are easily extended. Queries can be nested and saved.

3.1.6 Additional Aspects of Qualification

The language supports partial qualification on a search value. For example:

Find any supplier whose name begins with 'X'.

```
SUPPLY /  S#/ SNAME   /.../
------/----/--------/---/
     /    / P.'X'_Y/   /
```

Joins can be performed based on partial qualification.

3.2 Retrieval and Presentation

The result of any query can be printed or displayed with column headings and column widths under user control. Output can be selected from multiple tables. Column order and sort order can be modified dynamically for output.

3.2.1 Database Queries

Queries can be saved and nested.

The result of any query is a relation. The language is relationally complete insofar as the required algebraic operations are expressible.

3.2.2 Retrieval of Information about Database Constituents

System tables may be queried. Data is retrievable from all such tables using the normal query facilities.

3.2.3 Retrieval of System Performance Data

Nothing found.

3.2.4 Report Generation

The system will print table images of any output.

3.2.5 Constraints and Limitations

The only constraints are imposed by a DBA or by the user who created a table through the authority mechanism.

3.3 User perception of data for all alteration operations is tabular.

3.3.1 Insert Facilities

Table definitions and user created tables can be altered by insertion. The user perceives constituents as tables.

Insertion of tables and columns has been described in prior sections of this report (See Section 2).

Tuple insertion - simple

Insert a new row in the SUPPLY table.

SUPPLY	S#	SNAME	STATUS	CITY
I.	S4	AJAX		N.Y.

Key columns (attributes) must be unique. Non-KEY columns can be null. Any blank column entry is interpreted as null.

Query-dependent insertion

Insert into PART a part whose number is P7 which has the same name, color and weight as part P4.

PART	P#	PNAME	COLOR	WEIGHT
	P4	_X	_Y	_Z
I.	P7	_X	_Y	_Z

Insertion into one table can be dependent upon a query against another table. See, for example Section 3.3.2.

3.3.2 Delete Facilities

Table contents and tuples of user created tables can be deleted.

Simple deletion - the operation can be performed selectively on a row basis.

Delete all data on red parts.

PART	P#	PNAME	COLOR	WEIGHT
D.			RED	

Query dependent deletion -

Delete all suppliers from the SUPPLY tables who supply any part weighing less than 10 lbs.

SUPPLY	S#	SNAME	...
D.	_X		

SPJ	S#	P#	J#	QTY
	_X	_Y		

PART	P#	PNAME	COLOR	WEIGHT
	_Y			< 10

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3.3.3 Modify Facilities

Simple update -

Update the supplier city for S4 to N.Y.

```
SUPPLY / S#   / SNAME / CITY / STATUS /
______________________________________
      /      /       /      /        /
 U.  /  S4  /       / N.Y./        /
 P. /      /       /      /        /
```

Note: The P. requests the system to display the table after the change is made.

Query - dependent update

Increase the weight of all red parts by 10%.

```
PART   /  P#   / PNAME / COLOR / WEIGHT    /
____________________________________________
      /      /       /       /           /
     / _P1  /       /       / U1.1*_S1 /
    / _P1 /       /  RED  /       _S1/
```

3.3.4 Commit and Undo Facilities

As described in 3.4.5 when a transaction is not committed, it is backed out.

3.4.1 Arithmetic and String Operations

Already covered in Section 2. Also, the system supports text search on columnar data including facilities for "don't care" or "universal match" logic.

3.4.2 Sorting

Both ascending and descending sorts with up to 12 sort "keys" are possible in a single query. Sorting occurs for presentation of data only.

3.4.2 Library Function

MIN, MAX, CNT, SUM, AVG.

Count unique (UN.) and count every (ALL.) are supported.

3.4.4 User Defined Functions

Higher level functions are defined as queries. This takes the form of:

I. query

The query is executed via an X. query command, and can be updated with screen contents using the U. query command.

3.4.5 Transactions

A transaction terminates when it is committed by the user. A SAVE command can be used explicitly to force an end of transaction for stored queries.

3.4.6 Multi-attribute Alterations

Multiple tuple alterations are supported along with query-dependent alteration as noted in previous sections.

3.4.7 Grouping

Grouping is supported.

Print the number of each supplier and the total quantity of parts supplied by each.

```
SPJ  / S#   / P# / J# / QTY         /
___________________________________
    /      /     /    /            /
   / P.G /     /    /P.SUM.ALL./
```

4.0 Definition, Generation and Administration Facilities

4.1 Definition Facilities

Data definition for all database constituents is part of a single uniform mechanism as described in prior sections.

4.1.1 Constituents of a Database Definition

Tables, Columns, Data Characteristics (system term=attributes), snapshots, stored queries, database directory.

4.1.2 Database Definition

Already described in prior sections of this report.

4.1.3 Relation Definition

As described in prior sections.

4.1.4 View Definition

As described in prior section 2. No query or update constraints on operations performed on snapshots.

4.1.1 - 4.1.8

As described in prior sections.

4.2.1 Constituents of a Database Generation

Database, tables (relations), columns (attributes), rows (tuples), domains.

4.2.2 Generation of Database Constituents

QBE load program (bulk loader), IMS extract program, and facility for developing static views, SNAPSHOTS.

4.3 Database Redefinition

The databases and their constituent tables can be redefined dynamically.

4.3.1 Renaming Database Constituents

Changes to table names and column names can be performed dynamically as already described in previous sections. (Changes to domain characteristics can also be performed dynamically. These changes are automatically posted to system tables by the system).

4.3.2 Redefining Database Constituents

New columns (attributes) can be added to unpopulated tables dynamically. Tables already populated with data can be expanded by defining a new, static view (SNAPSHOT).

Table names must be unique. Column names need not be unique.

4.4 Database Regeneration and Reorganization

4.4.1 System-controlled

Except for updates to the system tables already noted, none known.

4.4.2 DBA-controlled

The DISK and DESCRIBE commands and the bulk loader already described are the only facilities found.

4.5 Database Dictionary

The system supports limited directory facilities as already described. Constituents of this directory are updated automatically by the system. Users can read entries on any database constituents they are authorized to read. Other changes to the directory are under system/DBA control.

The language for querying the dictionary is the same as for querying other database constituents.

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5.0 Interfaces and DBMS Architecture

5.1 System Architecture

The DBA is sensitive to and has ultimate authority over all tables. One can say, therefore, that the DBA view corresponds to the conceptual view of the data.

User views correspond roughly to external views.

5.2 Interface Descriptions

At the logical level the primary interface is QBE, either tabular or linear syntax as already described. All database constituents are available and all database processing functions are expressible. The tabular language is interactive and is user driven. This self-contained language is complete in the sense already noted.

6.0 Operational Aspects

6.1

6.1.1 Access Control

The user gains access to the system through a user I.D. and password. (This is the CMS protocol). Once the user is logged on, QBE corroborates the I.D. which implies authorization to see various database constituents. Private relations can be defined as snapshots and supported as "private" through the normal authorization mechanism.

6.1.2 Capability

Security is supported to the column level and can be value based. Any valid QBE qualifier can be used to define authorization.

The user specifies constraints as queries against tables by keying the keyword AUTH in the TABLE NAME column. Options are:

- Print authority
- Update authority
- Delete authority
- Insert authority

Authority can be granted on a column basis and can be value based.

6.2 Physical Integrity

Concurrent reading of the database is supported. Only a single user has write access to a database at any given time.

6.2.2 Crash Recovery

QBE uses a transactions concept in which copies of old and new data are both maintained until transaction completion time. This assures that system failure will not leave the data base in a state of partial modification.

Facilities exist for periodic backup of the QBE data base. In addition, all storage modification activity is separately logged and available for QBE recovery in the event of data base damage.

6.3.1 Operating Environment

When used interactively Query-By-Example statements go through a screen manager which sends to the parser a linear string mapping of the 2-Dimensional syntax. The parser in turn passes control to the data base processor which evaluates the queries dynamically to optimize the search. Thus the Data Base processor is an interpreter. The access module of Query-By-Example is the IBM Cambridge Scientific Center XRAM, which maintains indices dynamically.

QBE executing under control of IBM Virtual Machine Facility /370 using facilities of Control Program (CP) and Conversational Monitor Program (CMS). VM/CMS requirements include the System Extensions Program Product 5748-XB1 of the Basic System Extension Program Product 5748-XX8. If remote 3277 terminals are used, the VM/370 control program must include the fix for APARS VM07289 and VM08338.

Since part of QBE was written in PL/I, execution requires access to the PL/I Transient Library (IBM Program Product Number 5734-LM5).

6.3.2 Hardware Environment

The system runs on IBM S/370 MOD-135 and up. For tabular language input, the system requires the IBM 3277-II. Any teletypewriter terminal supported by VM-CMS can be used for linear (string) input. File media is disk. VM-CMS is required.

The system appears to exhibit:

1. Simplicity - Data objects are always relations and functions are basically based on the few operations of the relational algebra, although the language is, in general, best viewed as a relational calculus language.

2. Uniformity - A single language supports data definition, database changes, retrieval and authorization.

3. Data independence - The language is highly data independent and non-procedural. The user is virtually totally free of constraints of representation at the storage level except, as has been noted, where data TYPE must be known.

4. Symmetry - The system appears to take advantage of the symmetry of the relational model.

5. Security - Security constraints are specified using the power of the QBE qualifying expressions.

RAPID
Feature Analysis

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January 1981

Contents:

1 INTRODUCTION

1.1 Identification

RAPID is a database management system (DBMS), by which is meant a set of software that provides tools to describe, create, control and access data files in a direct access environment. The name "RAPID" is an acronym: Relational Access Processor for Integrated Databases, which reflects the essential aspects of the system.

"Relational" refers to the theoretical data model on which the system is predicated. This model was first popularized by E.F.Codd of IBM and since has been well discussed in the literature (see particularly C.J.Date: An Introduction to Database Systems: Addison Wesley). The "relational" approach differs from others primarily in the simplicity of its basic file structures and the fact that relationships are defined dynamically at the time of retrieval of data rather than when the data is stored.

"Access Processor" defines the primary function of the software. It provides a simple means of access to data for the user of utilities as well as the application programmer and designer of customised software.

"Integrated Databases" are the object of, and the product of any DBMS. The words have become commonly misused in the recent past so we shall state our understanding of the terms. By "integrated" we mean that RAPID manages both data descriptions (meta-data) and the application data itself. It provides access to this information by a consistent set of facilities which ensure the integrity between the data and its description. By "database" we mean any collection of RAPID files which are seen by the user as being related in some way. A database evolves as new application functions are added or as separate databases are integrated (connected) into a common application.

Thus RAPID performs the function of the storage model upon which a variety of query processors have been built. The most important feature of RAPID is that it does not presume to be a system with integrated query languages etc. as assumed by the RTG-80-81 paper. It is simply a system that supports a wide variety of query processors. This feature has allowed RAPID to be interfaced with a number of commercially available report-writers and statistical packages, and will allow it to support relational languages as they become available.

To fully comply with the RTG-80-81 guidelines, Sections 2, 3, and 4 of this document would have to be completed for each query processor listed in Section 1.6. This is an onerous task, and not particularly relevant to the purpose of RAPID. Thus, the facilities provided by the RAPID nucleus to support the query processors will be described in Sections 2, 3, and 4. Query processors use different subsets of the facilities to provide languages and higher level functions appropriate to the user group for which they are intended.

1.2 Status

1.2.1 System

RAPID has been operational since 1975 and is installed in various government agencies in Canada, United States, Sweden, Brazil, East Germany and Hungary. The United Nations, through CELADE (Centro Latinoamerica de Demografia) which is part of the Economic Commission for Latin America, has installed RAPID at its headquarters in Santiago, Chile and in Costa Rica. RAPID is not available to the private sector.

The nucleus of RAPID is stable, with most development being done in the area of interfaces and utility packages. RAPID is fully supported by Systems Development Division of Statistics Canada.

1.2.2 Applications

There are about 9,000 Megabytes of data currently stored in RAPID relations at Statistics Canada. RAPID has been used in a variety of applications, but its primary use has been in databases subject to frequent statistical queries which access few attributes and many tuples (often millions).

A benchmark of RAPID against ADABAS and TOTAL in 1979 showed RAPID to be:

STRONG	COMPARABLE	WEAK
sequential retrieval	data compression	random updates
database loading	record deletion (keys)	
sequential update	keyed retrieval	
field additions		
record deletion (no keys)		
access path creation		
size limitations		

RAPID places some limits on the size of its relations:

2,147,483,647	tuples per relation
536,870,811	attributes per relation
65,536	tracks per relation (BDAM)
4,294,967,296	bytes per relation (VSAM)
19	relations open at one time per user

1.3 System Background

RAPID evolved from a tabulation system (STATPAK) used at Statistics Canada since 1971 where data was stored in an essentially relational form as transposed files (each attribute was a direct access dataset) with inherent maintenance problems. The transposed file concept was married with ideas for self documenting data and database technology in the development of "String Files for TOTAL" in 1973.

"String" files were used to process several applications, including the 1974 Test Census of the Population of Canada. Analysis of that application showed that the concepts were sound, but that performance was a major factor in processing statistical queries (millions of tuples for few attributes). RAPID was developed in 1975 in response to anticipated performance problems in an environment with an abundance of practical experience, statistical methodology, database theory, research facilities, skillful programmers, and good management.

The first major application of RAPID was to process the 1976 Census of the Population of Canada (1100 Megabytes of data). Analysis of the processing characteristics on large relations led to a major update of RAPID software in 1977 to improve performance and to prepare for a virtual storage environment.

1.4 Overall Philosophy

The most important criterion in the development of RAPID was to separate the data storage mechanism from the query processors. Query processors include all those commercial and home-made report writers, statistical tabulators, and interactive browsing mechanisms that are currently installed or might be installed at Statistics Canada. In the developers' opinion, a relational query processor can be built on a hierarchical data storage mechanism only with restrictions, but a hierarchical query processor can be built on a relational storage mechanism without restriction.

Other objectives included:

1. Flexibility - the system must support a variety of different views of the data.

2. The separation of relations such that independently designed relations can be JOIN'ed based on data content.

3. The ability to provide high performance access for statistical queries (many tuples - few attributes). Very good performance would be needed for informational queries (medium subset of tuples and attributes), and performance for operational queries (few tuples - many attributes) could be sacrificed if needed.

4. The ability to have self-documenting files that can be used on a stand alone basis without access to a data dictionary. (Hammond's Postulate: any pair of datasets will get out of step in todays operating systems.)

5. To allow for dynamic (by applications during execution) creation and deletion of attributes, tuples, and access paths without any need for reorganization. This includes adding additional space as needed to the datasets.

6. To provide data compression, particularly for attributes whose domains have a small range with little ability to identify (qualitative) such as sex, marital status, credit status, etc.

7. To provide a single interface with execution time binding of all applications (including query processors) to the database software.

8. To provide open time binding of applications to the database with options of read only, update, or update with logging for each relation.

9. To support user specified data representations for all common data types.

10. To provide an external data dictionary for query processors and other high level functions. This dictionary must not be required for the nucleus to function.

1.5 Essentially Relational Characteristics

RAPID supports the structural aspects of the relational model and provides facilities for insert, update, and delete operations, as well as the data access facilities needed to build or interface to a data sub-language. Primitives are defined for manipulating relations, while JOIN's and other inter-relational operations are not implemented in the RAPID nucleus.

Various data-manipulating systems have been built using RAPID, and each uses a subset of the relational algebra operators.

It is significant to note that JOIN's have been done without any restriction (cycles, JOIN's to the same relation and more than one JOIN between two relations).

1.6 Interfaces

RAPID provides a host language interface which is used by both application programs and RAPID utilities. Because of this common interface, a number of programs developed for specific application systems have been adopted as RAPID utilities.

RAPID commands may be invoked from any host language which supports the CALL facility. Currently, facilities are available to simplify and standardize usage from PL/I and COBOL. Users of other host languages follow the COBOL instructions.

The interface between RAPID and PL/I is different in that it uses compiler and execution facilities not supported by any other host language.

In the following classification of interfaces, the primitive commands which one would normally use in the programming of such an interface are listed first and those packages which supply the function to higher level users are briefly described. This paper will not go into detail on any of these packages as to do so would require excessive space and would not provide a true understanding of what we feel is the essential nature of RAPID. Later sections will describe the primitives in more detail and for convenience an index is given in Section 1.8 of available commands and their function.

1.6.1 Database Schema Definition

Commands: $DEFN, $KYDF, $WTUA, $WTVL

MDM - Meta-Data Memory - data dictionary

1.6.2 Query Language

Commands: $DEFQ, $DELQ, $FIND, $KYRT, $SCAN

DREAM - Direct REIational Access Method - online relation browsing

RML - Relational Manipulation Language - online/batch utility for manipulating relations

1.6.3 Database Altering

Commands: $STOR

LOADGEN - generate subroutines for custom programs

RAPMERGE - merge sequential files onto relations

RAPUPD - online updates

1.6.4 Constraint Definition

RML - Relational Manipulation Language

1.6.5 Database Generation and Re-generation

Commands: $REFM

INITRELN - allocate and format disk space

1.6.6 Database Schema Redefinition and Renaming

Commands: $RNAM

1.6.7 Report Generation

Commands: $RETR, $SEQR

DREAM - online query processor for browsing relations

EASYTRIEVE - vendor product plus interface

EXTRACTO - vendor product plus interface

PATTERN - frequency distribution of values in attribute

SAS - vendor product plus interface

SPSS - vendor product plus interface

STATPAK - batch tabulation system

TPL - Table Producing Language - U.S. Bureau of Labor Statistics package plus interface (under development)

1.6.8 Data Entry

None.

1.6.9 Security Definition, Monitoring and Control

Commands: $FCTL, $STPR

AUDIT - detects alterations to data by attribute

1.6.10 Database Control

UNLOAD - dump relation to sequential dataset

RELOAD - restore relation from UNLOAD'ed dataset

TRANSFER - physical copy from relation to relation

BACKOUT - restore relation to beginning of log file

RECOVER - restore relation to a checkpoint

TRAMP - online execution of primitive commands

1.6.11 Definition of Storage Structure, Indexes and Access Paths

Commands: $INDX, $KYDF, $KYAD, $KYDL

KEYGEN - generate/delete access path

1.6.12 Database Dictionary

Commands: $RDMD

MDMUPDT - online/batch dictionary update

MDMREAD - online browsing of dictionary

MDMPRNT - batch formatted display of dictionary

1.6.13 Special Purpose Language

Because of RAPID's self-documenting files, many application systems have been built with tailor-made languages for retrieval, tabulation, updating and other functions.

1.7 Documentation

1. "Database File Design," Systems Development Division, Statistics Canada, Ottawa, June 1976.

2. "RAPID DBMS," Systems Development Division, Statistics Canada, June 1978.

3. "RAPID Language Reference Manual," Systems Development Division, Statistics Canada, Ottawa, May 1978.

4. "RAPID Meta-Data Memory," Systems Development Division, Statistics Canada, Ottawa, June 1978.

5. "RAPID Database Creation," Systems Development Division, Statistics Canada, Ottawa, June 1978.

6. "RAPID Programmer's Guide," Systems Development Division, Statistics Canada, Ottawa, May 1978.

7. "RAPID Retrieval," Systems Development Division, Statistics Canada, Ottawa, June 1978.

8. "RAPID Utilities," Systems Development Division, Statistics Canada, Ottawa, June 1978.

9. "Database Performance Manual," Systems Development Division, Statistics Canada, Ottawa, October 1978.

10. "ADABAS/RAPID Demonstration Database," Systems Development Division, Statistics Canada, Ottawa, June 1978.

11. Podehl, W. M. "STATPAK - General Concepts and Facilities," Systems Development Division, Statistics Canada, Ottawa, 1972.

12. Turner, M. J. "A New File-Type for TOTAL or How and Why Statistics Canada Has Widened the Scope of the TOTAL DBMS," Systems Development Division, Statistics Canada, Ottawa, December 1972.

13. Turner, M. J. "The Impact of Data Bases on Statistical Agencies," Systems Development Division, Statistics Canada, Ottawa, January 1974.

14. Turner, M. J. "Data Management at Statistics Canada," Systems Development Division, Statistics Canada, Ottawa, March 1975.

15. Turner, M. J. and Podehl, M. "GSS Plans For a Generalized Database Management System," Systems Development Division, Statistics Canada, Ottawa, October 1975.

16. Turner, M. J. and Hammond, R. and Cotton, P. "A DBMS for Large Statistical Databases," Systems Development Division, Statistics Canada, Ottawa, September 1979. VLDB5 pg 319-327.

1.8 General System Description

Each primitive command has a five character name beginning with "$". They will be referenced by name frequently throughout the rest of this document and are summarized below. These are commands available from the various host languages, e.g. PL/I and COBOL.

Environment commands:

- $CLOS - close a relation
- $DQUE - release resources
- $DUMP - dump control blocks
- $FCTL - retrieve file control information
- $OPNx - open a relation
- $QIES - create recovery point
- $REFM - delete all attributes and tuples
- $STPR - display performance statistics

Meta-data commands:

- $DEFN - define attribute
- $DELS - delete attribute or access path
- $KYDF - define access path
- $RDCD - retrieve attribute description
- $RDMD - retrieve meta-data from relation or dictionary
- $RDUA - retrieve user area
- $RDVL - retrieve domain
- $RNAM - rename attribute or access path
- $WTUA - write user area into attribute meta-data
- $WTVL - write domain into attribute meta-data

Data manipulation commands:

- $DEFQ - define query for future use by $FIND
- $DELI - delete index value(s)
- $DELQ - delete query previously defined
- $FIND - find next index at which query specified by $DEFQ is true
- $INDX - allocate index value(s)
- $KYAD - add new key/index couplet
- $KYDL - delete key/index couplet
- $KYRT - retrieve key/index couplet
- $RETR - retrieve data cell(s) for specified index
- $SCAN - find next index with exact match on specified element value(s)
- $SEQR - retrieve data cell(s) for index beyond specified index
- $STOR - store data cell(s) for specified index

Program facility commands:

- $CDED - create data element descriptor
- $CELM - convert data element
- $DEFR - define logical record
- $DELR - delete logical record definition

2 DATABASE CONSTITUENTS

2.1 General Description

As mentioned in Section 1, a RAPID database and its constituents are more a characteristic of an application program or query processor than the storage model. For example, the STATPAK system usually views its data as a hierarchy of geographic areas which contain zero or more households which contain zero or more persons. As an intelligent processor, it also knows that there are three relations, and when processing a query that only involves some attributes of persons for all tuples it ignores the heirarchy and views only the specified attributes of the "person" relation.

For ease of explanation to non-data processing oriented users, the following terms are frequently used:

CELL - the value for a particular tuple for a particular attribute.

COLUMN - an attribute.

CURSOR - a synonym for INDEX.

DATABASE - the collection of relations currently being accessed.

DOMAIN - the collection of values that may appear in an attribute.

FILE - relation.

INDEX - an arbitrary pointer to a tuple, maintained by RAPID to force uniqueness among tuples. See also CURSOR.

KEYTREE - an access path used for performance in direct access of tuples by data values in attributes.

RECORD - the set of values for a subset of attributes being viewed for a particular tuple in a particular relation.

ROW - tuple.

2.2 Database

2.2.1 Database Structure

This is left completely to the application, although each relation is maintained as a self-documenting entity in an O/S dataset.

2.2.2 Database Operations

This is generally left to the application, but there are two database commands:

$QIES - flush all RAPID buffers and (optionally) place a recovery point record on the log file.
$DQUE - close all relations (optional recovery point) and release all RAPID resources.

2.2.3 Database Constraints

RAPID stores data in a variety of formats, and sizes within formats. When a query processor navigates between relations, it is responsible for ensuring appropriate data conversions.

2.2.4 Additional Database Properties

Application dependent.

2.3 Relation

2.3.1 Relation Structure

A RAPID relation is a collection of tuples and attributes whose existence is maintained independently; if it has neither it is considered empty and not available for read-only access. When a new attribute is defined on a relation with existing tuples, access to the new cells returns null values although they do not physically occupy space. Similarly, new tuples automatically have null values for all attributes. "Duplicate" tuples are allowed, as each is assigned an arbitrary, unique, INDEX value which is used during access. Attribute order is not significant, except that a list of attribute names is used to define a RECORD during processing, and retrieve/store accesses maintain the defined order. Alias attribute names are not allowed, and duplicate attribute names are allowed in a RECORD, and on different relations.

2.3.2 Relation Operations

A relation is created and its disk space formatted with the INITRELN utility. Additional disk space may be added at any time with the EXPAND utility, and excess space freed back to the operating system with the RAPRLSE utility. Attribute descriptions may be moved between relations and the data dictionary through a copy command in the data dictionary processor. RAPID primitive commands at the relation level include:

- $OPNx - open relation for processing in read-only, update, or update with logging mode.
- $CLOS - terminate processing and release resources.
- $FCTL - determine status of a relation, including counts of tuples and attributes.
- $RDMD - retrieve a list of names and descriptions of attributes.
- $DEFQ - define a query which will be used to locate tuples. The query specifies names of attributes, relational operators, constant values, etc.
- $FIND - locate a tuple which satisfies the query.
- $DELQ - delete a query definition.

2.3.3 Relation Constraints

A KEY is a set of data values which must exactly match the cells of the associated attributes to identify a tuple. This is a dynamic process, so there may be duplicate keys; thus a KEY/INDEX couplet is required to uniquely identify any given tuple. In some processes, the INDEX alone is used as the key.

In RAPID, KEY/INDEX couplets may be stored in a special type of column (attribute?) where they are kept in ascending sequence of data value and accessed by binary and sequential searches ($KYAD - add key, $KYDL - delete key, and $KYRT - retrieve key). Keytrees are defined with $KYDF, and deleted with $DELS. The names of the member attributes may be retrieved with $RDVL. These "keytrees" are easily generated at any time with the KEYGEN utility application, based on any attribute or combination of attributes.

Due to RAPID's transposed organization, keytrees are only needed for random access against very large relations, as the $SCAN command (search for exact match of data values) is very efficient.

2.3.4 Additional Properties of Relations

Experience at Statistics Canada has shown:

1. That users perceive themselves as data processing specialists.
2. That they most readily understand "flat files" (relations in at least first normal form).
3. That they would like to view data as a hierarchy.
4. That a variety of hierarchies must be imposed on the same data.

The last point is the key to the advantages of the relational storage model. A wide variety of hierarchies can be supported without duplication of data, just as it is in the "real world".

2.4 Views

2.4.1 View Structure

Just as a database is the collection of relations being accessed, a VIEW is a subset of attributes and tuples with their navigation paths within the database. Views are very dynamic, and may be data dependent (e.g. MARRIED FEMALES). The difference between views may be as subtle as a different data format (e.g. SALARY as FIXED DEC(11,5) or FLOAT DEC(6)).

With RAPID, the nature and limitations of views depends on the application or query processor, but the primitive commands supply a number of facilities for views within a relation.

2.4.2 View Operations

The meta-data commands may be used to determine the feasibility of a view and navigation paths. Within a relation, a number of RECORD's may be defined ($DEFR) which name the attributes and data formats in which the cells are to be materialized. Tuples may then be stored from or retrieved into a program work area matching the definition.

2.4.3 View Constraints

Each execution of a command results in a status being returned to the application which may then be interpreted for its meaning in a particular logical circumstance. For example, if a program which is looking at old data views SALARY as a FIXED DEC(5) value and the attribute has a 7 digit domain, a warning will be issued by $DEFR; but data may be retrieved until a value of more than 5 digits is encountered, when a value of null and a further message will be returned.

2.4.4 Additional Properties of Views

It is easy to define views on a single relation, as demonstrated by most commercial products dealing with flat files. Products supporting multi-relation DYNAMIC views with simple syntax are not readily available. Is the concept of VIEW is more complex than it seems, or is the technology just in its infancy?

2.5 Tuple

2.5.1 Tuple Structure

A tuple is a row which currently exists when a relation is viewed as a table with rows and columns. It seems meaningless, but tuples may exist even if no attributes exist. As mentioned earlier, each tuple has an INDEX or cursor for unique qualification.

2.5.2 Tuple Operations

Tuples are allocated and freed with the $INDX and $DELI commands; and assume a null value for all existing attributes when first allocated. The INDEX of a tuple may be determined with the $FIND, $SCAN, $KYRT, and $SEQR commands. Actual cells in a tuple are retrieved and stored with the $RETR, $SEQR and $STOR commands.

2.5.3 Tuple Constraints

Tuples are not ordered (except by INDEX) and may not appear unique. RAPID's lack of constraints on tuples places a burden on query processors. Some utility applications (RAPMERGE for example) insist on a unique key on some combination of attributes.

2.5.4 Additional Properties of Tuples

In a transposed organization, for performance, it is often preferable to determine the tuples in a set to be viewed as a list of INDEX's, sort the list in ascending INDEX order, retrieve the data cells (tuples) in INDEX order, and re-sort as needed as a flat file for ordered processing.

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2.6 Attribute

2.6.1 Attribute Structure

An attribute is a column, when a relation is viewed as a table with columns and rows, and attributes exist independently of tuples. Each attribute has a domain which is one of its characteristics along with data type, size, precision, etc. The name of an attribute (limited to 8 characters) is specified when it is allocated, and alias names are not supported.

2.6.2 Attribute Operations

Attributes are allocated and freed with the $DEFN and $DELS commands. At the time of definition, its physical characteristics of data type, size and precision are specified, yielding a default domain. Each cell (row/column intersection) for the attribute assumes a null value until updated with a $STOR command. The characteristics are partially used for data compression in RAPID. For example, FIXED BIN(3) is a two byte value when viewed from PL/I, but is stored by RAPID in 4 bits. Other commands allow the user to further restrict the domain ($WTVL) and store application oriented meta-data about the attribute ($WTUA). A number of commands are available to retrieve attribute meta-data.

Systems programmer commands are available to access segments of columns (a large number of tuples for a particular attribute). This is used mostly for boolean operations in the application between columns defined as LOGICAL (each cell occupies one bit).

Attribute descriptions are normally moved between relations and the data dictionary through a copy command in the data dictionary processor.

Other attribute operations are an application function of the query processor in use, typically operating at the tuple level.

2.6.3 Attribute Constraints

Attribute constraints are limited to ensuring that a value to be stored is within the domain of the attribute. Violations result in a status message, and the storing of a null value.

2.6.4 Additional Properties of Attributes

Ideally, attribute characteristics should be defined only in terms of their domain. Unfortunately, characteristics such as FIXED, FLOAT, BINARY, DECIMAL, CHARACTER, CHARACTER VARYING with appropriate SIZE and PRECISION values are needed to communicate with todays host languages.

2.7 Domain

2.7.1 Domain Structure

In RAPID, a domain is the set of values that may be stored in a particular attribute. The default domain is the range of values allowed by the data type and size of the attribute. The user may further restrict the domain by supplying ($WTVL) a list of values (or ranges of values) which is stored with the attribute's meta-data. A value of null will always be found as part of the domain specification.

RAPID has two special attribute types, LOGICAL and CODED. A LOGICAL attribute is a single bit wide, and has an implicit domain of TRUE and FALSE where FALSE is also null. A CODED attribute's domain is an ordered list of value names. A CODED attribute's values are stored as unsigned binary numbers in a minimum number of bits and used as an index into the list to return the value name (data compression).

2.7.2 Domain Operations

The only domain operations are the meta-data commands used for their storage and retrieval.

2.7.3 Domain Constraints

Value names are limited to 16 characters, and all values are constrained by the data type of the associated attribute. In the data dictionary, attributes of different type and size may share the same domain (CODESET), and keywords are used to represent boundary values (e.g. MAX - the highest positive number the data type will allow).

The domain is used by the $STOR command to ensure that only valid values are stored on a relation. Violations result in the storing of a null value in the cell and the returning of a status indicator.

2.7.4 Additional Properties of Domain

Some data types are better than others at supporting the null value concept. For example, FLOAT allows more than one representation of zero so that null can be identified from zero, but FIXED does not allow such luxury.

2.8 Additional Database Constituents

None.

3 FUNCTIONAL CAPABILITIES

3.1 Qualification

As expressed earlier, the functional capabilities to be described in this section apply more to a query processor or other application program than to the storage model. There are a number of such processors used with RAPID, and the only capabilities that will be discussed are those primitive commands used in their development.

3.1.1 Restriction

The $DEFQ command is used to specify a restriction on a relation, followed by $FIND commands to locate the tuples which satisfy the query. The queries are named, so that many queries can exist concurrently for the same relation. If the query is coded as a literal, the maximum length of the literal string is 256 characters, but when specified as a program variable, there is no limit on the length of the character varying variable.

The query string is composed of query elements combined with the "&" and "|" boolean operators. Each query element is coded in one of the following formats:

(i) Attribute1 OP Constant
or
(ii) Attribute1 OP Attribute2
or
(iii) Attribute1 or ¬Attribute1

where "Attribute1" and "Attribute2" are attributes on the relation, "Constant" is a numeric or character constant, and "OP" is one of the following comparison operators:

=, >, >=, <, <=, ¬=, ¬>, ¬>=, ¬<, ¬<=

In case (i), the constant must conform in type to the attribute.

Fixed-point numeric constants (RAPID types "FB" and "FD") are written as an optional "+" or "-" sign followed by one or more decimal digits containing an optional decimal point. The number of digits following the decimal point should be the same as specified by the precision of the attribute (see $DEFN). If not, digits following the decimal point are truncated or padded with zeroes as necessary according to the precision of the attribute.

Floating-point numeric constants (RAPID types "EB" and "ED") are written as a fixed-point numeric constant followed by the letter E, followed by an optionally signed decimal integer exponent.

Character constants (RAPID types "CH" and "CV") are contained in either single quotes or double quotes (the double quote character ") with no imbedded quotes of the same type. Character constants may also be specified in hexadecimal by coding X' followed by a sequence of hexadecimal digits, with each group of two representing a byte, followed by ' (end quote). Since PL/I also uses the single quote as a delimiter in character strings, all single quotes within the query string must be doubled if it is coded as a PL/I literal.

Coded constants (RAPID type "CD") must be specified as the 16 byte character code value. Coded attributes must have standard domains as created by the MDM copy command.

Logical constants (RAPID type "LO") may be represented as either quoted character strings "TRUE" and "FALSE" or numeric 1 and 0. Only the "=" and "¬=" comparison operators are valid in query elements involving logical attributes.

In case (ii), the respective attributes to be compared must be of the same type and scale, although not necessarily of the same length (i.e. the RAPID types must be identical). Coded attributes are handled internally using the character code value and may be compared with character attributes. When comparing character attributes of different lengths, the shorter character value is padded to the right with blanks before comparison.

In case (iii), "Attribute1" must be a logical attribute (i.e. it must have a RAPID type of "LO"). These two formats, respectively, are simply shorthand ways of writing: Attribute1 = "TRUE" and Attribute1 = "FALSE".

The "&" and "|" boolean operators apply between two query elements or groups of query elements enclosed in parentheses. Normally the query string is evaluated left to right with no priority of operator. However, groups of query elements may be enclosed in parentheses to define priority of evaluation. The group of query elements enclosed in parentheses is evaluated as a unit prior to applying the logical result of this unit with the adjacent query element. A "¬" boolean operator may be specified before a left parenthesis to reverse the logical result of the following parenthesized expression.

Evaluation of the query string follows the normal rules of boolean algebra (except that there is no priority of operator). Query elements which have no bearing on the result of the query are not evaluated (e.g. if the accumulated logical result of the query is true and the current boolean operator is an |, evaluation of the next query element is skipped). Hence, the query string can be optimized if the query elements which best determine the truth of the entire expression are placed near the beginning of the query string.

The syntax of the query string is essentially free format. Blanks are not significant except within character constants.

<u>Examples</u>

```
    $DEFQ FILE('RELN') NAME('QUERY1')
          QUERY('PROJECT="RAPID" & LRECL>=BLKSIZE');

    $DEFQ FILE('RELN') NAME('QUERY2')
          QUERY('RECFM="FB" & (OWNER="XYZ" | OWNER="ABC")');

    $DEFQ FILE('RELN') NAME('QUERY3')
          QUERY('TEST & ¬(RECFM="FB" | LRECL<80)');

    $DEFQ ('RELN','QUERY4','FLOATCOL < .3E-2 & OWNER = "O''BRIAN"');
```

3.1.2 Quantification

This is normally accomplished by a series of $FIND or $SCAN commands. The INDEX is used to start at the "top" of the relation and proceed toward the logical end of file at which time a special status is returned.

3.1.3 Set Operations

Application function.

3.1.4 Joining

Application function.

3.1.5 Nesting in Closure

Application function.

3.1.6 Additional Aspects of Qualification

The highest level of qualification is specification of the relations. With RAPID, the user connects (through JCL or TSO command) the dataset name and DDNAME. The DDNAME is then connected to the RAPID file name through the $OPNx command.

3.2 Retrieval and Presentation

3.2.1 Database Queries

The $FIND command returns the INDEX of a tuple which satisfies a query definition ($DEFQ - Section 3.1.1). A special case of that facility exists in the $SCAN command with which the user supplies a workarea containing the exact match values for the attributes which will satisfy the query. The $SEQR command may be used to retrieve the INDEX's of tuples in their arbitrary physical sequence, and the $KYRT command may be used to retrieve the INDEX's in logical ascending order for a direct access path.

3.2.2 Retrieval of Information about Database Constituents

Information about database constituents is known as meta-data in RAPID. Some of the meta-data commands are:

- $FCTL - count of tuples, attributes, date of last update, etc.
- $RDMD - access meta-data from either a data dictionary or a relation. Includes list of attribute names, their characteristics, domains, etc.
- $NXTK - answers the question "Does a particular attribute exist?" without physical access to meta-data.
- $RDUA - retrieve application oriented meta-data (user area) about an attribute.

3.2.3 Retrieval of System Performance Data

The $STPR command may be used to display current processing statistics for use in performance evaluation. This command may also be issued by the $CLOS, $DQUE and $QIES commands. The $FCTL command returns some statistical data and the amount of free space currently available.

3.2.4 Report Generation

Stand-alone packages with interfaces to RAPID include EASYTRIEVE, EXTRACTO, SAS, SPSS and soon TPL. STATPAK is a major home-made statistical tabulation package which functions only with RAPID. DREAM is an example of a generalized application program which has become a RAPID Utility. It is intended as a query processor for online browsing, but is frequently used for batch reporting.

3.2.5 Constraints and Limitations

Application function.

3.2.6 Additional Aspects of Retrieval and Presentation

There are a number of commands which return the INDEX of a tuple, but actual retrieval of data values is done only by $RETR, and $SEQR using a supplied INDEX value. This anomaly exists in RAPID commands because many queries are satisfied by knowledge that something exists without need of retrieval, a performance benefit in a transposed structure.

3.3 Alteration

3.3.1 Insert Facilities

A view in RAPID is a transient entity which is attached to the application and exists only between its definition ($DEFR command) and its explicit ($DELR) or implicit ($CLOS, etc.) deletion. Attributes, domains, and tuples may be added at any time ($DEFN, $WTVL, and $INDX).

3.3.2 Delete Facilities

In RAPID, every allocation command has a corresponding deletion command. Thus views, attributes domains and tuples may be dynamically deleted. The $REFM (reformat) command is available to instantly delete all attributes and tuples. Space freed by the delete commands is automatically reused by later insert commands.

3.3.3 Modify Facilities

As described earlier, the cells of data initially have null values. They are updated with the $STOR command. The application meta-data associated with an attribute may be retrieved ($RDUA) modified and replaced with the $WTUA command.

3.3.4 Commit and Undo Facilities

A checkpoint may be taken at any time, and the RECOVER utility used to restore the database to a specified checkpoint.

3.3.5 Additional Alteration Facilities

A functional deficiency of RAPID is that the access paths (keytrees) are not automatically maintained when $STOR updates a data cell. Some applications have turned this "deficiency" into a feature with which they create application dependent special access paths.

3.4 Additional Functional Capabilities

Application function.

4 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

A RAPID database is dynamic, composed of the set of relations currently being viewed, and a subset of attributes and tuples within the relations.

4.1.2 Database Definition

Implicit, by opening a relation for processing:

```
$OPNL FILE('S') NBUF(4);
```

4.1.3 Relation Definition

A RAPID relation is essentially a repository for attributes and tuples. Foreign keys are frequently used with RAPID, and may be defined ($KYDF) but typically accessed through the $SCAN command. See Section 4.1.6.

4.1.4 View Definition

See Section 2.4.

4.1.5 Tuple Definition

See Section 2.5. To allocate a single tuple, a variable is needed for the INDEX value which will be returned:

```
DCL  CSR   FIXED BIN(31) INIT(-1);
$INDX FILE('S') INDX(CSR) RANGE(1);
```

4.1.6 Attribute Definition

Normally, users create a RELATION description in the MDM (data dictionary) and use its copy command to define the attributes and their domains on a relation. The MDM processor is simply a generalized application using the host language interface being described here. See Section 2.6. To allocate the "SNAME" attribute on relation "S":

```
$DEFN FILE('S') NAME('SNAME') TYPE('CV') SIZE(100);
```

4.1.7 Domain Definition

See Section 4.1.6. This is supported by the $WTVL command which is almost never used outside of generalized software. It can be coded as follows:

```
DCL    1     VALTAB,
         5  (ENTRY_CNT       INIT(03),
             ENTRY_LEN       INIT(18),
             KEY_LEN         INIT(16),
             KEY_POS         INIT(01)) FIXED BIN(31),
         5   ELEMENTS(3),
          10 VALU_NAME       CHAR(16)
                             INIT('BLUE','GREEN','RED'),
          10 VALU_CODE       FIXED BIN(15)
                             INIT(1,2,3);
$WTVL FILE('P') NAME('COLOUR') FROM(VALTAB);
```

4.1.8 Definition of Additional Database Constituents

Primary and secondary (foreign) access paths may be defined with the $KYDF command:

```
$KYDF FILE('S') NAME('$KEYPRIM') CLMS('S#,END.');
```

4.2 Generation Facilities

4.2.1 Constituents of a Database Generation

To generate a database, an application must allocate relations that do not currently exist, and possibly a data dictionary.

4.2.2 Generation of Database Constituents

Allocation of space for the example relations would typically be done in a TSO session:

```
RAPSTART
INITRELN S
INITRELN P
INITRELN SP
```

Since there is a small volume of attributes and tuples, the RAPUPD Utility would typically be used to define attributes, tuples, and populate the relations. Other Utilities for populating a relation include:

```
RAPMERGE - loading from a flat file.
RAPCOPY  - copy complete relations.
RML      - project a view of a relation onto a new relation.
```

4.3 Database Redefinition

4.3.1 Renaming Database Constituents

All users must be aware of name changes. Each relation is an O/S dataset, and may be renamed with standard system functions.

To rename an attribute, the $RNAM command may be used:

```
$RNAM FILE('P') OLDNAME('COLOUR') NEWNAME('COLOR');
```

4.3.2 Redefining Database Constituents

The ability to create and delete attributes, tuples and to some degree domains has been described elsewhere. Redefinition typically involves creating the new, copying from the old, deleting the old and renaming. Programs which properly define their view are insulated from most changes as described in Section 2.4.3.

Additional space may be added to relations (EXPAND utility) and excess space released (RAPRLSE) without moving or reorganizing data.

4.4 Database Regeneration and Reorganization

4.4.1 System-Controlled

Not required.

4.4.2 DBA-Controlled

In general, there is no need to reorganize a properly normalized relational database. The DBA may need to change the physical characteristics of relations, for example, when moving relations (datasets) to new devices. This is supported by the RAPCOPY utility, and such changes are transparent to all users.

4.5 Database Dictionary

RAPID has, in effect, a distributed database dictionary. Information normally starts off in the MDM (Meta-Data Memory) and is COPYed to relations so that changes to the MDM will not impact existing data. MDM is long overdue for replacement, but its' simplicity and flexibility make it hard to replace. In simplified terms, the user defines sets of entities (RELATION, FILE, CODESET, STUBSET, etc.). Instances of the entities are named, and contain a list of elements, each with a comment. Some standard entity sets have specific formats (e.g. RELATION). This meta-data may be accessed by programs using the $RDMD command.

The example could be stored in MDM as follows:

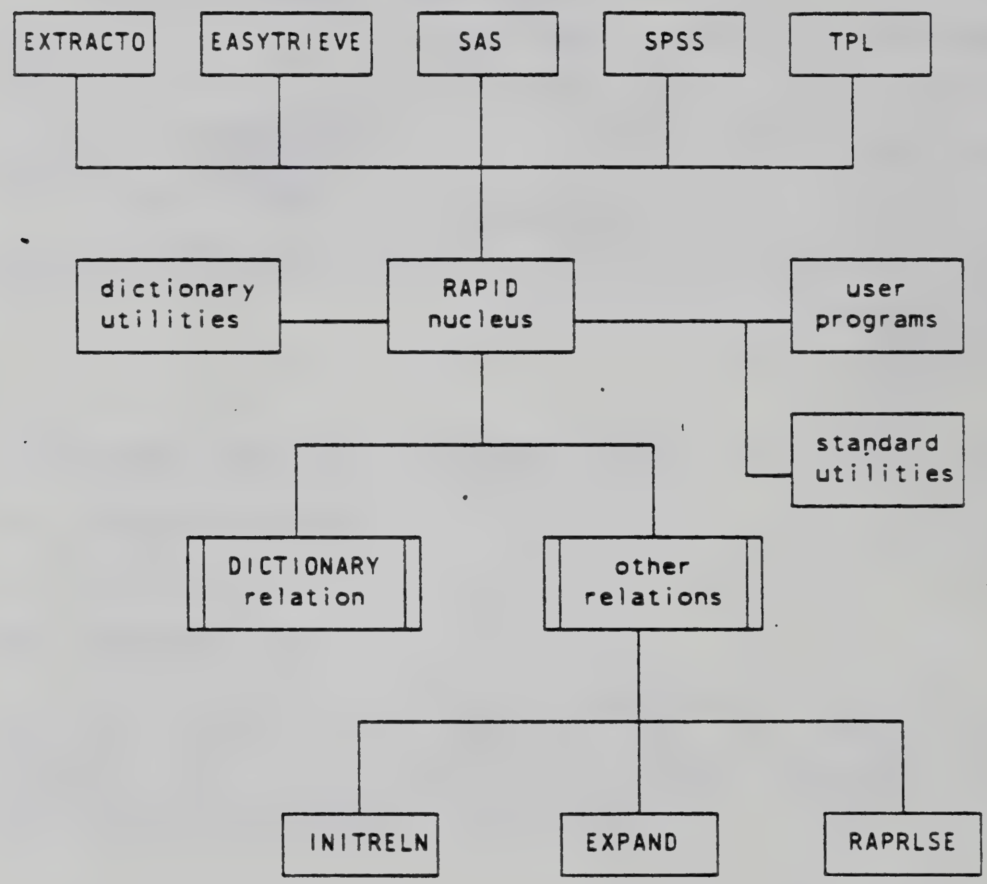
```
RELATION  P         KEY(P#)
          P#        CHAR(2)             PART NUMBER
          PNAME     CHAR(10)            PART NAME
          COLOUR    CODED(COLOUR)       COLOUR OF PART
          WEIGHT    FIXED BIN(23,2)
          CITY      TEXT(50)

VALUESET  COLOUR
          RED
          GREEN
          BLUE
```

5 INTERFACES AND DBMS ARCHITECTURE

5.1 System Architecture

All utilities and application programs access relations through a common system interface with two entry points ($INTER using the PL/I execution environment, RAPLNK which simulates a partial PL/I environment for non-PL/I users).

Stand-Alone Packages with RAPID Interfaces



Space Management Utilities

5.2 Interface Descriptions

5.2.1 PL/I Interface

The PL/I pre-processor facilities are used to provide a set of statement macros that simplify and standardize the use of RAPID primitive commands. The commands are expanded into a CALL statement to a common entry point to the RAPID nucleus, followed by the testing of the returned status code as needed. For example, a command coded as follows:

```
$RETR FILE('reln') CLMS('alpha,beta,gamma,end.')
      INDX(csr) INTO(workarea);
```

is expanded to the following form:

```
DO;
   $OP='$RETR';
   $FILE='reln';
   CALL $INTER($OP,$STAT,$FILE,csr,
             'alpha   beta    gamma   end.     ',workarea);
   IF SUBSTR($STAT,1,1)¬='*' THEN
      SIGNAL CONDITION($ERROR);
END;
```

NOTE: Lower case was used to demonstrate the macro expansion and is not used normally.

5.2.2 COBOL Interface

All RAPID primitives can be invoked from a COBOL (or other language) program, through the CALL statement. The parameters are defined so as to be identical to the corresponding PL/I CALL statement. Checking the returned status code is the responsibility of the application program. Data is communicated through work areas defined in the application program.

6 OPERATIONAL ASPECTS

6.1 Security

6.1.1 Access Control

RAPID does not contain security mechanisms. In practice, the operating system password facility is used to protect relations (which are contained as one relation per O/S dataset) where necessary. This can be done at the WRITE PROTECT or READ/WRITE PROTECT level. If a dataset is password protected to prevent WRITE access, a security violation is recorded if any attempt is made to open the relation in update mode ($OPNU or $OPNL). At Statistics Canada, such events are passed to the security office for attention.

6.1.2 Capability

As described above, each relation can be protected at the O/S dataset level if required. Thus, relations are considered to be security domains in this context.

6.2 Physical Integrity

6.2.1 Concurrency Control

RAPID makes no provision for concurrency while updating because of the limited need to update statistical databases, and the significant cost of concurrency to readers. Application programs and utilities require exclusive control of relations being updated.

6.2.2 Crash Recovery

Backup and restore utilities (UNLOAD, RELOAD, RAPSYNC) are available which operate on single relations.

RAPID provides "before image" logging for relations opened in logging mode ($OPNL). Database checkpoints may be taken with the $QIES command, but restarting of program logic is the responsibility of the application.

Utilities are available to undo updates to a particular checkpoint (RECOVER) and to restart by recovering to the beginning of the log file (BACKOUT). These operations may become primitive commands at some future date.

6.3 Operating Environment

6.3.1 Software Environment

RAPID requires an IBM operating system such as MVS, VS1, MVT, or the equivalent. TSO (Time Sharing Option) is required for interactive execution of the RAPID Utilities. The RAPID nucleus is coded in re-entrant assembler and makes use of BDAM (and soon VSAM) access methods for relations and BSAM for logging. It makes few other demands on the operating system. RAPID utilities are for the most part coded in PL/I with some assembly language subroutines.

At execution time, RAPID will make use of PL/I transient routines for dynamic space allocation and message IO transmitters, sharing such with the application PL/I host. This sharing of the PL/I environment has led to simplified debugging of both application programs and the RAPID nucleus.

6.3.2 Hardware Environment

RAPID requires an IBM 370 or compatible CPU. No firm measurement of memory requirements can be given, but 32K plus RAPID internal buffers is a guideline. In general, RAPID becomes more efficient as more storage is given for internal buffers (it pages data to and from disk using sophisticated algorithms) and it is not uncommon to see RAPID applications using 500K to more than 1M of storage.

RAPID relations may be stored on any direct access device supported by the operating system.

Logging requires an additional sequential file, and this may be either tape or disk.

7 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS

7.1 Simplicity

In RAPID each relation is seen as a two dimensional matrix of rows (tuples) and columns (attributes). The greatest advantage this has given is that all segments of the data processing community understand the data concepts.

7.2 Uniformity

No comment.

7.3 Data Independence

RAPID emphasizes the importance of data independance, both in the implementation and the written guidance provided with it. In particular, the self-documenting feature of RAPID files is of great importance in providing robustness to RAPID application systems.

7.4 Permits Optimization

The combination of a relational storage model and transposed organization have allowed RAPID to transfer only the needed data between the application and database. This limits response time to the speed of the cpu, which is unusual in a database system. For example, a STATPAK tabulation which accessed two attributes for nearly 25 million tuples executed in five minutes on an Amdahl V6. In RAPID applications, optimization of queries and the navigation between relations has been left to the application system designers. The logical independence of normalized files provides substantial opportunity to ensure that the design of application systems can permit future optimization, as "hard" linkages are seldom built into code.

7.5 Basis for High-level Interfaces

At present, relatively little has been done to build high-level, multi-relational generalized programs. Experience with single relation utilities and soft-coded application systems which process many relations, has shown the ease with which future developments can take place. In particular, RAPID's use of self-documenting files and dynamic database definition facilities have provided much needed tools for system builders.

7.6 Natural

Once explained, normalization of files is usually understood by most people to be a worthwhile simplification, and as such, normalized files are seen as a "natural" representation of data.

7.7 Efficient Storage and Retrieval Potential

RAPID was designed for processing of very large statistical databases. Most queries tend to address relatively few columns, and very many rows. The transposed file design of RAPID is directed towards this environment. The storage of meta-data with the attributes allows the system to provide effective data compression transparent to the user. Somewhat surprisingly, performance compares very favourably with several commercial record-oriented DBMS packages, except in random update mode in particular circumstances.

7.8 Multiple Views of Data

Within a relation, RAPID supports selective processing of the various attributes without regard to other attributes that may be present. Automatic data conversion facilities which permit an application program to operate independently of the physical storage definition used, will soon be released. Since each relation is independent and self-documenting, databases can be formed as the user requires.

7.9 Advantages for Distributed Databases

RAPID is not to be considered for use in a distributed environment, other than as a base from which subsets are transferred to and from local systems.

7.10 Security

Access restrictions are not supported in RAPID. Physical security is simple and effective.

7.11 Basis for Database Semantics

We are planning a major development at Statistics Canada, which will begin with a machine-readable catalogue of surveys, publications, data files and so on. The relation will be a fundamental unit of data to be described within this catalogue, and will thus be the cornerstone of an overall organization of data. This catalogue will evolve into a conceptual schema describing the bureau's data processing applications.

7.12 Strong Theoretical Foundation

The advantages of working with normalized files has been stressed throughout this evaluation, and should need no further emphasis at this point.

8 DATABASE APPLICATIONS USING RAPID

8.1 Applications at Statistics Canada

8.1.1 Census of Population

RAPID was used for the processing of the Canadian Census of Population in 1976, and will be used again for the 1981 Census. The Census database consists primarily of two very large relations; one with 24 million tuples, each one corresponding to an individual, and a second with about 8 million tuples, each one corresponding to a household. The editing and imputation is performed by a generalized processor known as CANEDIT, against sections of the database known as work units. Update activity ceases once the editing is complete.

The Census database is used extensively in read-only mode for the production of a very large number of tabulations designed both for publication and for internal use. The majority of these tabulations are produced by the semi-generalized package known as STATPAK. This utility is designed around the known structure of the database, but can accept very generalized specifications of the tabulations required. The transposed file design of RAPID contributes to the efficient processing of this large number of tabulations.

8.1.2 Intercorporate Ownership

This database contains information about the mutual and foreign ownership of business corporations within the Canadian economy. It consists of a pair of relations; the first containing one row for each corporation above a defined size, and a second in which each row describes a directed ownership link between a pair of corporations.

Various application programs can then follow ownership chains that may be of any degree of complexity. In particular, many-to-many linkages, and even loops occur, and can be processed effectively.

It is interesting to note that the logical design of this database was highly confused until a decision was made to normalize the file design. At that point, most of the logical difficulties disappeared, and the revised design was seen to be much "cleaner" and more understandable to all personnel assigned to the project.

8.1.3 Consumer Price Index

The C.P.I. is an important measure of the performance of the Canadian economy. The database consists of one main relation containing the time-series data in a matrix form with the time dimension mapped into the attribute names and the city and item dimensions mapped onto the tuples. Other relations describe the cities, items, and imputation rules. It is estimated that this particular file design using RAPID provides a fifty fold gain in performance in critical areas of the application when compared to the original design using TOTAL.

The monthly phases of production are: priced data loading, imputation, aggregation, and retrievals. Currently, data from January 1974 is kept online in a database requiring 100 Megabytes of disk storage, but provision is made to archive and reload any number of months of the oldest data on the database.

Items, cities and their aggregate structures may be updated as necessary with the only limitation being that no more than 1052 items may be defined. This limit was chosen as a further optimization so that the data for each city on the main relation does not straddle RAPID segment boundaries and cause excessive paging by the RAPID buffer management algorithms. The aggregate structures of items and cities are maintained in keytrees on the respective relations. This non-standard use of what is meant to be an access path is tolerated by the RAPID nucleus and eliminated the need for what would have been two very trivial relations.

8.1.4 Record Linkage

Considerable progress has been made towards a generalized record linkage utility that uses RAPID as an intrinsic part of its internal processing mechanism. This package has been used to link disease incidence files with mortality records to determine statistical information such as survival rates.

Much more work in this area is anticipated in the future.

8.2 Applications Outside of Statistics Canada

8.2.1 CELADE

Centro Latinoamerica de Demografia is part of the Economic Commission for Latin America, a United Nations subsidiary. CELADE installed RAPID in 1978 and developed the SPSS (Statistical Package for the Social Sciences - SPSS Inc., Chicago) interface.

The WFS (World Fertility Survey) has been conducted in 35 countries, and data for 5 countries has been loaded on RAPID databases. The data typically involves over 500 attributes and 5000 tuples per country. End users process the data directly through SPSS, typically through the batch facilities of OS VS1 on IBM 148 machines.

8.2.2 Census of Population in Brazil

Fundacao Instituto Brasileiro de Geografia E Estatistica (the Brazilian statistical office) is using the RAPID/STATPAK combination for the tabulation of their recent Census of Population in the same way as they were used in Canada.

8.2.3 U.S. Bureau of Labor Statistics

The Bureau of Labor Statistics is currently developing an interface with their very powerful Table Producing Language (TPL) package. There is some hope that this combination will eventually replace the use of STATPAK at Statistics Canada.

8.2.4 Agriculture Canada

The Canada Soil Information System has several RAPID databases composed of some 30 relations. One of the databases is accessed from coast to coast through a service bureau network.

Feature Analysis of RAPPORT

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Feature Analysis of RAPPORT

Abstract

The RAPPORT database management system is described using the "Feature catalogue of relational concepts, languages, and systems", Working paper RTG-80-81 of the Relational Database Task Group of the ANSI/X3/SPARC Database System Study Group.

Acknowledgement

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Contents

1. Introduction

1.1 Identification

RAPPORT is a database management system based on the relational model. It was designed by LOGICA, a British software house (64 Newman Street, London W1A 4SE).

1.2 Status

1.2.1 System

Used in-house by LOGICA since 1977. Released as a product in October 1979. Second release in July 1980. Some features are still being implemented.

MICRO RAPPORT was released in November 1980 : it is a subset of RAPPORT installed on a Z80-based microcomputer system. MICRO RAPPORT supports the retrieval and updating commands provided by RAPPORT. Backup and recovery, data security and other RAPPORT options are not implemented in MICRO RAPPORT.

1.2.2 Applications

Existing applications include: financial planning, computer aided design, stock control, project management, scientific analysis.

1.3 System Background

1.4 Overall Philosophy

See Section 1.8.

1.5 Essentially Relational Characteristics

RAPPORT provides file (= relation) definition, an embedded and a stand alone data manipulation language with update operations. It does not support the so-called "insert-update-delete" rules referred to in the feature catalogue.

The stand alone language is not relationally complete and the embedded language relies on the power of the host language (FORTRAN, COBOL or CORAL) for reaching the power of the relational algebra. Remarkably, RAPPORT does not have a dedicated join operation. It is thus not "fully relational".

1.6 Interfaces

The interfaces to RAPPORT offer the following capabilities:

- database definition at the logical level and at the physical level (storage structure, indexes, access paths);
- database interactions (retrieval and updating) via an embedded language and via a stand alone interactive

language;
- database generation;
- multi-user access and data integrity through a locking scheme;
- data security by passwords and encryption
- utilities:
  - backup and recovery
  - statistics gathering on usage of database and of storage structures
  - fast loading and unloading of data

1.7 Documentation

Logica documents include :

- Introduction to RAPPORT
- RAPPORT designing and using a database
- RAPPORT user manual
- RAPPORT interactive query language user manual
- RAPPORT system managers manual

1.8 General System Description

RAPPORT is a portable DBMS for applications in FORTRAN, COBOL or CORAL environments on mainframe, mini and micro computers.

RAPPORT is a flat file system, which provides the power of relational operations through relatively simple languages.

RAPPORT probably lies at the borderline of what can really be called "relational".

Interesting aspects of RAPPORT appear to be its relative simplicity, portability and physical data independence.

2. Database Constituents

2.1 General Description

Term Translation Table

Rapport term	Feature Catalogue term
file	relation
record	tuple
field	attribute
field name	attribute name

A RAPPORT database consists of a collection of named files (=relations). A file consists of a collection of records (=tuples) of identical type. A record consists of a collection of fields (=attributes) of possibly different types. A field is denoted by a name (=attribute name). A field type (=attribute type) can be a FORTRAN standard type (real or integer) or a one-dimensional array thereof.

2.2 Database

2.2.1 Database Structure

A database is a collection of files (=relations) whose structure is defined in a schema (RAPPORT Database Definition File). A database does not have a name.

2.2.2 Database Operations

Operations are provided for defining and generating a database. Some database reorganizations are supported by utility programs. Files and indexes can be defined or deleted after database generation.

There is no direct RAPPORT command to destroy a database.

2.2.3 Database Constraints

Database constraints are defined on the file (=relation) and on the field (=attribute) level. They consist essentially in the definition of keys.

2.2.4 Additional Properties

2.3 Relation

2.3.1 Relation Structure

The predominant perception of a relation is as a flat file of records of identical structure or as a table. A file is identified by a name. Duplicate tuples are not allowed. Attribute order is insignificant.

2.3.2 Relation Operations

The operations on files (=relations) are:

- retrieval of a record (=tuple) given a conjunction of simple conditions on its fields (=attributes);
- group retrieval within loops (see Section 3.2.1);
- updating of one or several records (=tuples) in a file (=relation);
- insertion of one record (=tuple) at a time in a file (=relation);
- deletion of one or several or all records (=tuples) in a file (=relation).

There is no command for removing a relation from the schema.

2.3.3 Relation Constraints

Primary keys must be specified for each file (=relation). Primary key violations result in run-time errors in application programs: insertion or update of a record (=tuple) that would lead to the duplication of a primary key value in a file (=relation) is not executed. (In the host language interface, this error is signaled by a return code associated with the insertion or update operation; in the stand alone interactive language, this error is signaled by a message).

2.3.4 Additional Properties of Relations

2.4 Views

RAPPORT does not support views. However, it is possible to give particular users access to only a part of the database. Such a database part has to be a whole file (=relation).

2.5 Tuple

2.5.1 Tuple Structure

- A record (=tuple) consists of a collection of named fields (=attributes).
- Field names (=attribute names) must be unique within the whole database. (At the FORTRAN programming interface a tuple appears as a collection of FORTRAN variables).
- A mechanism exists to select individual tuples for read and write purposes (see the FETCH command in Section 3.2.1 and the STORE command in Section 3.3.1).
- Keys are defined by tagging one or more fields in the file definition as defining the primary key.

2.5.2 Tuple Operations

From the point of view of the update and retrieval operations, tuples are treated as records in a file. However, neither the host language interface nor the stand alone interactive language provide operations for handling a tuple as a single entity.

At the embedded language interface, a tuple is represented by a collection of variables (one for each attribute). There is exactly one such "tuple" per database relation, acting as a data buffer between the application program and the DBMS. Reading, updating and writing a tuple in a relation is made via this buffer. RAPPORT provides a loop construct for enumerating all the tuples satisfying a Boolean condition in a relation; at each execution of the loop body, a new tuple value is made available in the relation buffer. Notice that this tuple value is associated with a relation and not with a particular loop; thus nested loops on the same relation share the same buffer.

2.5.3 Tuple Constraints

2.5.4 Additional Properties of Tuples

In the manual "RAPPORT : designing and using a database", it is stated that a record (=tuple) usually describes some entity (the fields of the record describing the attributes of the entity).

However, a database design philosophy based on an entity-relationship also seems to be advocated in this manual : such a design philosophy more naturally leads to represent entities as relational domains.

Anyhow no design strategy is actually privileged or supported by the system.

2.6 Attributes

2.6.1 Attribute Structure

Attributes have a type and a name (=attribute name). The type of fields (=attribute types) are FORTRAN types (<u>integer</u>, <u>real</u>, or a one-dimensional array thereof). Alias field (=attribute) names can be defined for the use in the stand alone interactive language.

It is possible to indicate that an integer field or array is to hold a character string for use in the stand alone language.

2.6.2 Attribute Operations

The relational comparison operators can be used for comparing fields (=attributes) of records (=tuples) possibly from different files (=relations). Comparisons can be combined to form conjunctions. No compatibility check is done for the embedded language, and the FORTRAN rules for coercion (or type conversion) apply; in the stand alone interactive language, a comparison of two fields (=attributes) is allowed only if both fields are defined on the same underlying type.

There is no direct operation to drop, add or remove a relation attribute.

2.6.3 Attribute Constraints

Using the embedded language, field (=attribute) names have to be unique within the whole database, whereas field names in the interactive environment only have to be unique within the file (=relation) they are defined in.

Size constraints can be defined indirectly on an integer field by specifying in the database schema that the field is to be packed into n bits. An attempt to store an integer that cannot be represented in n bits results in a run-time error. (For the treatment of run-time errors, see Section 3.4.8).

In a RAPPORT schema, one can specify that the key of a file (=relation) is a single integer field ranging from 1 to N. Attempts to store a record (=tuple) with a key value outside the defined interval results in a run-time error.

2.6.4 Additional Properties of Attributes

If an entity is viewed as a tuple, then the relational attributes describe properties of the entity (see Section 2.5.4).

2.7 Domain

User-defined or application-dependent domains are not supported.

Field (=attribute) types are constrained to be one of the FORTRAN standard types (see Section 2.6.1.).

Null, unknown and undefined values are not supported : they are the responsability of users.

2.8 Additional Database Constituents

3. Functional Capabilities

The facilities for selecting and manipulating database constituents are available in two kinds of languages:

- embedded languages with FORTRAN, COBOL or CORAL as a host language;
- a stand alone interactive query language.

The capabilities of both kinds of interfaces are in general very similar. Their main difference is that the embedded languages always return an error test variable after execution of a RAPPORT command which can be used afterwards by control statements in the programming language environment. (In the following this variable is named ITEST). The interactive query language does not provide that facility. The subsequent presentation concentrates on the FORTRAN embedded language. Local dissimilarities with the stand alone interactive language are mentioned when applicable. All examples refer to the RAPPORT file definitions as stated in Section 4.1.2.

3.1 Qualification

Records (=tuples) satisfying some Boolean condition are delivered one at a time in a loop (SEARCH loop) or by repeated execution of a FETCH statement.

The retrieved values (field of the records) can be further used in other selection operations. The selection mechanism is thus procedural or navigational.

3.1.1 Restriction

The comparison operators that can be used for restricting fields of records are: =, >=, >, <=, <, <>. A field can be compared with a FORTRAN, COBOL or CORAL expression (including a field of another record). In the stand alone interactive language, only comparison with a constant or a field of another record is allowed. Note

that the comparison between two fields of the same record (theta-restriction) is not allowed (or at least may not produce the intended result). The simple comparisons described above can be combined into a conjunction. Disjunction, negation and parentheses are not allowed.

Example of Selection

The tuples of the relation P(PPNUM, PPNAME, COLOR, WEIGHT, PCITY) where COLOR='GREEN' and WEIGHT is less or equal to 10 can be selected by the following SEARCH loop.

```
SEARCH P(COLOR .EQ. 'GREEN'; WEIGHT .LE. 10)

   {the selected tuples can be processed one at a time
    in the body of this loop}

ENDSEARCH (ITEST)
```

3.1.2 Quantification

No explicit quantifiers are available.

3.1.3 Set Operations

The power is there but they are not explicitly available.

3.1.4 Joining

Joining must be expressed procedurally with embedded SEARCH loops. There is no dedicated join operation.

Example: the join of SP(SPSNUM, SPPNUM, QTY)
with P(PPNUM, PPNAME, COLOR, WEIGHT, PCITY)
on matching partnumbers can be expressed as follows.

```
   SEARCH SP
```

```
      SEARCH P(PPNUM .EQ. SPPNUM)

            {the "joined tuples" are available one at a time
             in the body of this loop}

      ENDSEARCH (ITEST1)

   ENDSEARCH (ITEST2)
```

In the host language interface, there is no constraint on the compatibility of the join attributes; in the stand alone interactive language, the attributes must have the same representation.

A relation cannot directly be joined with itself in nested loops because only one buffer is statically allocated by RAPPORT for every database relation. In the host language interface, the desired effect can however be achieved by using host language statements for copying the relevant fields of the buffer into program variables.

3.1.5 Nesting and Closure

Despite the limitations mentioned in Sections 3.1.1 to 3.1.4, any qualification can be expressed using nested SEARCH loops, and the storage and control structures of the host language.

The stand alone language is not relationally complete and the embedded language relies on the power of the host language for reaching the power of the relational algebra.

3.1.6 Additional Aspects of Qualification

3.2 Retrieval and Presentation

3.2.1 Database Queries

The facilities for defining queries essentially consist of the capabilities for qualification described in Section 3.1. The predominant perception of retrieval operations is as follows: the records (=tuples) of a file (=relation) satisfying a Boolean condition can be accessed one at a time inside a loop; the values of these records (=tuples) can also be used for retrieving records of another file (=relation) in a nested loop. RAPPORT provides facilities for one-record-at-a-time queries as well as for queries that result in a variable number of records (=tuples). Record-at-a-time queries can be expressed by using the FETCH command, specifying uniquely the primary key in the conditions.

<u>Example</u>

```
      FETCH S ( ITEST ; SSNUM = 100 )

      IF ( ITEST .NE. 1 ) GOTO 1

      {code for handling the record fetched}

      STOP

 1    {exception handling procedure, e.g., if
      record is not found}
```

For queries that result in a variable number of records (=tuples) SEARCH loops are appropriate (see for example Section 3.1.1).

The tuples selected in a SEARCH can be delivered in the loop body in any user-defined ascending or descending lexicographic order. The required order is indicated by an optional ORDER clause prefixed to a SEARCH loop.

As described above, the result of a qualification operation is produced tuple by tuple. The output of these tuples is to be programmed by the user with the standard host language output statements. A special WRITE

statement is available in the stand alone interactive language (see Section 3.2.4).

There is no Boolean-valued qualification operation.

The embedded language has the power of relational completeness, but this power relies on control structures and temporary storage provided by the host language.

The stand-alone interactive language is not relationally complete. Its power can be roughly characterized as follows. Nested SEARCH loops on different relations can denote the Cartesian product of these relations (available tuple by tuple in the body of the innermost loop). The conditions in the arguments of the SEARCH loop are equivalent to a limited form of theta-restrictions on this Cartesian product (see limitations on the conditions of the SEARCH in Sections 3.1.1 and 3.1.4). Projection on the desired attributes of this restricted Cartesian product can be achieved by writing only the values of the desired attributes in the innermost loop.

3.2.2 Retrieval of Information About Database Constituents

In the interactive language, the HELP command can be used to retrieve the names of relations and their attributes.

3.2.3 Retrieval of System Performance Data

Commands of the embedded language are available for printing statistics about

- the physical dispersion of data within the database files
- the performance of accesses to each database relation by all the application programs during a given period (the number of logical retrieval operations and the number of physical read operations on disk per logical retrieval).

A detailed presentation of these statistics is not given here, since their understanding would require a presentation of the internal structure of RAPPORT, which falls outside of the scope of the Feature Catalogue.

This interface is not relational and is thus independent from the qualification capabilities described in Section 3.1.

3.2.4 Report Generation

RAPPORT does not have a real report generator. The form of the output document has to be specified procedurally.

Example of a program in the RAPPORT interactive language for printing as a table the name and status of the London suppliers:

```
WRITE ('---------------------------')

WRITE ('| SUPPLIER NAME | STATUS | ')

WRITE ('---------------------------')

SEARCH S WHERE ( CITY = LONDON )

WRITE ('| ',SUPPLIERNAME,' | ',STATUS,' |')

LOOP

WRITE ('---------------------------')

EXECUTE
```

Typical output of this program:

```
 --------------------------

 | SUPPLIER NAME | STATUS |

 --------------------------

 | SMITH         |  20    |

 | CLARK         |  20    |

 --------------------------
```

3.2.5 Constraints and Limitations

Limitations were mentioned in Sections 3.1.1, 3.1.4, and 3.2.1.

3.2.6 Additional Aspects of Retrieval and Presentation

3.3 Alteration

The altering facilities of RAPPORT are very similar to the traditional operations of insertion or update of a record in a file. A deletion facility for removing all the records of a file satisfying some Boolean condition is provided. Using the interactive query language, alterations are expressed as transactions. A transaction appears as a sequence of commands preceded by TSTART and followed by TEND (see Section 3.4.5).

3.3.1 Insert Facilities

Field (= attribute) values for a record (= tuple) which is to be inserted in a file are assigned in the record buffer which is associated to that file, and then stored in the database with the INSERT statement. The record buffer is filled by FORTRAN assignment statements or by previous database retrieval operations on the file to which the buffer is associated.

Example fragment of a program inserting a new tuple in the SP relation

```
SPSNUM = 547

SPPNUM = 4711

QTY    = 2
```

```
INSERT SP (ITEST)

IF (ITEST .EQ. 0) GO TO 1

     {here should come some code for treating exceptions
      occurring during INSERT, e.g., for handling the
      situation where a record with the same key already
      exists in the SP file}

1 ...
```

As it appears in the example above, exceptional conditions (e.g., a violation of a key constraint) are signaled by the DBMS to the application program by setting a user-defined test variable ITEST to a given error code.

In the interactive language, a SET assignment statement is provided for setting fields of the record buffer associated to a file to a constant value or to the value of a field of another record.

Example using the interactive query language for inserting the same tuple as above.

```
TSTART

     SET SP-SUPPLIERNO TO 547

     SET SP-PARTNO     TO 4711

     SET SP-QUANTITY   TO 2

     INSERT SP

TEND

EXECUTE
```

RAPPORT also has a STORE statement. It acts like an INSERT statement if the pre-specified values for the primary key of the record (=tuple) to be inserted do not already exist in the file (=relation). Otherwise STORE has the same effect as the UPDATE statement (see Section 3.3.3).

3.3.2 Delete Facilities

Records in a file that satisfy a Boolean condition (similar to that associated to a SEARCH loop) can be deleted.

<u>Example</u> delete all the records in SP where
PNUM is 4711

```
DELETE SP (N; SPPNUM .EQ. 4711)
```

This form of delete is the only truly set-oriented operation in RAPPORT.

The number of records which are actually deleted is returned as the value of the first argument (here variable N).

There is no distinction between unique record deletion by providing the key, and multiple record deletion.

<u>Example</u> delete the record of SP whose key is
SPSNUM=547, SPPNUM=4711

```
DELETE SP(N;SPSNUM .EQ. 547; SPPNUM .EQ. 4711)
```

All the records in a file can be deleted by the CLEAR statement. The result is an empty file, not a modified schema.

<u>Example</u> delete all records of SP

```
CLEAR SP(N)
```

3.3.3 Modify Facilities

Individual records in a file can be modified. The key values and all the other fields (updated or not) of a record to be modified must be present in the record buffer associated with the file before the UPDATE statement can start executing. This means in practice that the update of a record must be preceded by a retrieval of this record.

An update operation on a record (=tuple) identified by a key value that does not exist in a file (=relation) is an error. If a user is not sure whether or not a given key value exists in the file (=relation), he or she can use the STORE command. It results in an update if the key value exists and in an insertion if the key value does not already exist (see also Section 3.3.1).

Example update the city of supplier 50 to London

```
        FETCH S (ITEST; SNUM .EQ. 50)

        IF (ITEST .NE. 1) GO TO 1

        SCITY(1) = 'LOND'

        SCITY(2) = 'ON'

        UPDATE S (ITEST)

        IF (ITEST .NE. 0) GO TO 2

        ...

        STOP

  1     {code for handling the case of a record not found

        or other exceptions}

        ...

  2     {code for handling exceptions in update}

        ...
```

3.3.4 Commit and Undo Facilities

All updates in a transaction (see Section 3.4.5) can be "undone" before the end of the transaction by using a single BACKOUT command. In the stand-alone language, "COMMIT" is implicit at the end of a transaction. In the embedded language interface, "COMMIT" marks the end of a transaction.

3.3.5 Additional Alteration Facilities

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

The embedded language relies on the operations of its host language (FORTRAN, COBOL or CORAL).

The stand-alone interactive language does not have arithmetic or string operations (see however Section 3.4.3).

3.4.2 Sorting

The order (ascending or descending) in which the records (=tuples) are to be delivered in a SEARCH loop (in the embedded as well as in the stand-alone language) can be specified in an ORDER clause prefixed to a SEARCH loop.

3.4.3 Library Functions

The stand-alone language supports the functions MIN, MAX, SUM and AVERAGE. These functions can be applied to numeric fields of the records of a database file (= relation) or to a subset of records selected by Boolean conditions similar to those available to write SEARCH loops.

The function operates on all the values of a numerical field, and the result is put in the field with the same name in the buffer.

Example retrieval of the average weight of all screws in the file P (interactive mode)

```
AVG P ( PARTNAME EQ 'SCREW' )

WRITE ( "AVERAGE WEIGHT OF SCREWS IS ",WEIGHT )

EXECUTE
```

Additionally, the stand-alone interactive language provides the function COUNT, which returns the number of records (=tuples) in a file (=relation) satisfying a specified condition. If the condition is omitted, the total number of records (=tuples) in a file (=relation) is returned.

There is no facility for duplicate control and for repeated function application (grouping).

3.4.4 User - Defined Functions

User-supplied FORTRAN functions can be invoked from the interactive language. These "functions" can access the current values of the record buffer associated with each database file, modify these values, or produce other side-effects such as printing.

These functions are "global" to all the users of a database and the DBMS does not support authorization mechanisms for modifying these functions.

3.4.5 Transactions

A transaction is dynamically determined by the TRANSACT and COMMIT statements (TSTART and TEND in the stand-alone language). The DBMS automatically sets locks (preventing concurrent write or concurrent read) on the database files as soon as they are accessed in a transaction.

The user is aware of the concurrency of transactions in the sense that a transaction can be backed out ("undone") by the DBMS in the case of a deadlock.

3.4.6 Multi-tuple Alterations

Only a version of delete (see Section 3.3.2) operates on several tuples. Insert operates on one tuple at a time.

3.4.7 Grouping

There is no facility for partitioning sets of tuples, e.g. for repeated function applcation.

3.4.8 Exception Handling Mechanism

In the embedded language, the outcome of each database manipulation command is signaled to the application program in a variable which is passed as an argument of the command. The application program then has the responsibility to test this return code and take the appropriate exception handling decisions.

In the stand alone interactive language, each run-time error results in a message displayed to the user and generally also in aborting the execution of the current command. (Notice that the decision to undo the updates that have previously been performed in the current transaction unit is left to the interactive user.)

4. Definition, Generation, and Administration Facilities

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

A RAPPORT database definition (=schema definition) is specified by a special Database Definition File. It comprises definitions on the logical and physical level and specifies:

- the names of files (=relations);
- the names of fields (attributes);
- the type of fields;
- the primary key;
- the maximum number of records (=tuples) in a file (=relation);
- various physical information:
  - on access paths (relative addressing and hashing, declaration of secondary indexes including their expected selectivity);
  - on the mapping of relations and indexes on "physical" files (i.e., files known by the operating system);
- information on certain aspects of the system behavior.

4.1.2 Database Definition

A database is defined by a sequence of file (=relation) definitions (see Section 4.1.3). Special DBMS features can be invoked by an OPTION clause.

Example

```
OPTION

LIST; SORT

   {a listing of the preprocessed program will be
    produced and sorted retrieval is allowed}
```

Restrictions on the number of constituents, such as the maximum number of files, of fields per file, of indexes etc., have to be set up at DBMS installation time, but they can be changed by the database administrator.

Simplified Example of File Definition

This example shows how the files corresponding to the relations P(PPNUM, PNAME, COLOR, WEIGHT, PCITY), S(SSNUM, SNAME, STATUS, SCITY) and SP(SPSNUM, SPPNUM, QTY) could be described in a RAPPORT Data Definition File. The example is simplified in the sense that all access paths and physical aspects of the definition are omitted.

```
FILE P

FIELDS

        PPNUM; PKEY; 'PARTNO'

        PNAME(3); 'PARTNAME'; CHARS

        COLOR(2); 'COLOR'; CHARS

        WEIGHT; 'WEIGHT'

        PCITY(2); 'CITY'; CHARS

FILE S

FIELDS

        SSNUM; PKEY; 'SUPPLIERNO'

        SNAME(3); 'SUPPLIERNAME'; CHARS

        STATUS ; 'STATUS'

        SCITY(2) ; 'CITY'; CHARS

FILE SP
```

FIELDS

SPSNUM; PKEY; 'SUPPLIERNO'

SPPNUM; PKEY; 'PARTNO'

QTY ; 'QUANTITY'

Annotations:

- the default type for the field is one FORTRAN _integer_;
- the numbers between parentheses indicate the dimension of the fields (number of _integer_ or _real_ locations);
- PKEY indicates that field is part of the primary key of the file;
- the strings between quotes rename the fields for use in the interactive language;
- CHARS indicates to the interactive language processor that an _integer_ field in fact holds a character string.

4.1.3 Relation Definition

The definition of a file (=relation) states the file name and the maximum number of records (=tuples) in the file. It is followed by some optional definitions regarding physical properties and by the definition of the record fields (=attributes). Additionally, secondary indexes can be defined.

Example

FILE P

{file name is P}

RECORDS 1000; CHANNEL 2

{maximum number of records in file P is assumed to be 1000; the file will reside on disk file 2}

FIELDS

{followed by field definitions}

INDEX

{followed by the definition of the indexed fields}

4.1.4 View Definition

A kind of view definition (see however 2.4) is achieved by omitting definitions of certain files (=relations) in the Data Definition File. (There are physical restrictions which are not mentioned here.)

4.1.5 Tuple Definition

In the RAPPORT system, records (=tuples) are perceived as a collection of fields (=attributes) (see 4.1.3)

4.1.6 Attribute Definition

Field (=attribute) definition associates a field name with a field type. No user defined field types can be defined. Therefore field types are restricted to FORTRAN types (see 2.6.1 and 4.1.2). Additionally, information on the physical level can be specified and it can be stated whether or not the field is part of the primary key. For use in the stand-alone language additional definitions are required (see 4.1.2).

4.1.7 Domain Definition

User-defined domains are not supported. The possible field (=attribute) types are the FORTRAN standard types.

4.1.8 Definition of Additional Database Constituents

4.2 Generation Facilities

A database is generated in two steps. First the Data Definition File (=schema) is processed; then the result of this processing is used for generating the database physical files (that will contain the relations and their indices).

None of these facilities are "relational in nature".

4.3 Database Refefinition

4.3.1 Renaming Database Constituents

Not explicitly supported.

4.3.2 Redefining Database Constituents

The database relations can be individually redefined by modifying the database schema, selectively regenerating the physical files that are to hold them, and writing ad hoc programs for performing the reorganization (filling new relations from old ones).

4.4 Database Regeneration and Reorganization

Utility programs are provided for unloading, copying and loading files after the relations have been redefined.

4.5 Database Dictionary

Not supported.

5. Interfaces and DBMS Architecture

The functional capabilities listed in Section 1.6 are supported by the architecture described below. This architecture is described in terms of relationships between programs (system modules and utilities, application programs) and files (user supplied data such as the system representation of the compiled schema and the files constituting the database). System programs include :

- A utility for compiling a Database Definition File (see Section 4) into a Common File. The Common File is used by the Preprocessor and the run-time database handler (the RAPPORT Nucleus).

- A Security Structure Processor for compiling a Security Structure File (see Section 6.1). This utility also accesses the Database Definition File (see Section 4) and produces the Security Common File, which is used by the RAPPORT run-time Nucleus (the database handler).

- A New Password Processor for setting and modifying the passwords for access authorization and for encryption. It produces a new Security Common File. If encryption passwords are modified, the database is also accessed for performing the necessary re-encryption.

- A utility for (1) establishing the correspondence between RAPPORT logical files (=relations) and files known to the host operating system, and (2) specifying the maximum populations for each RAPPORT logical file.

- A Preprocessor translating the embedded database language into host language (e.g. FORTRAN) code and calls to the RAPPORT Nucleus (run-time database handler). The preprocessor accesses the Common File.

- The RAPPORT Nucleus, which satisfies the database manipulation requests issued by the application programs and the Interactive Query Language Processor and those interactively entered by the Database Administrator (requests for statistical informations, dumping, logging, recovery and roll-forward operations).

- The Interactive Query Language Processor

- Utility programs for initializing, physically reorganizing, copying, loading or unloading database files.

The diagram summarizes the architecture of RAPPORT. There are 3 types of nodes in the diagram :

1) Users (application programmers, Database Administrator)

2) Files (e.g. database schema, stored database files)

3) Processors (e.g. translators, database handler, application programs)

Arcs denote flows of data between the nodes.

The following are not included in the diagram :

- the utility programs

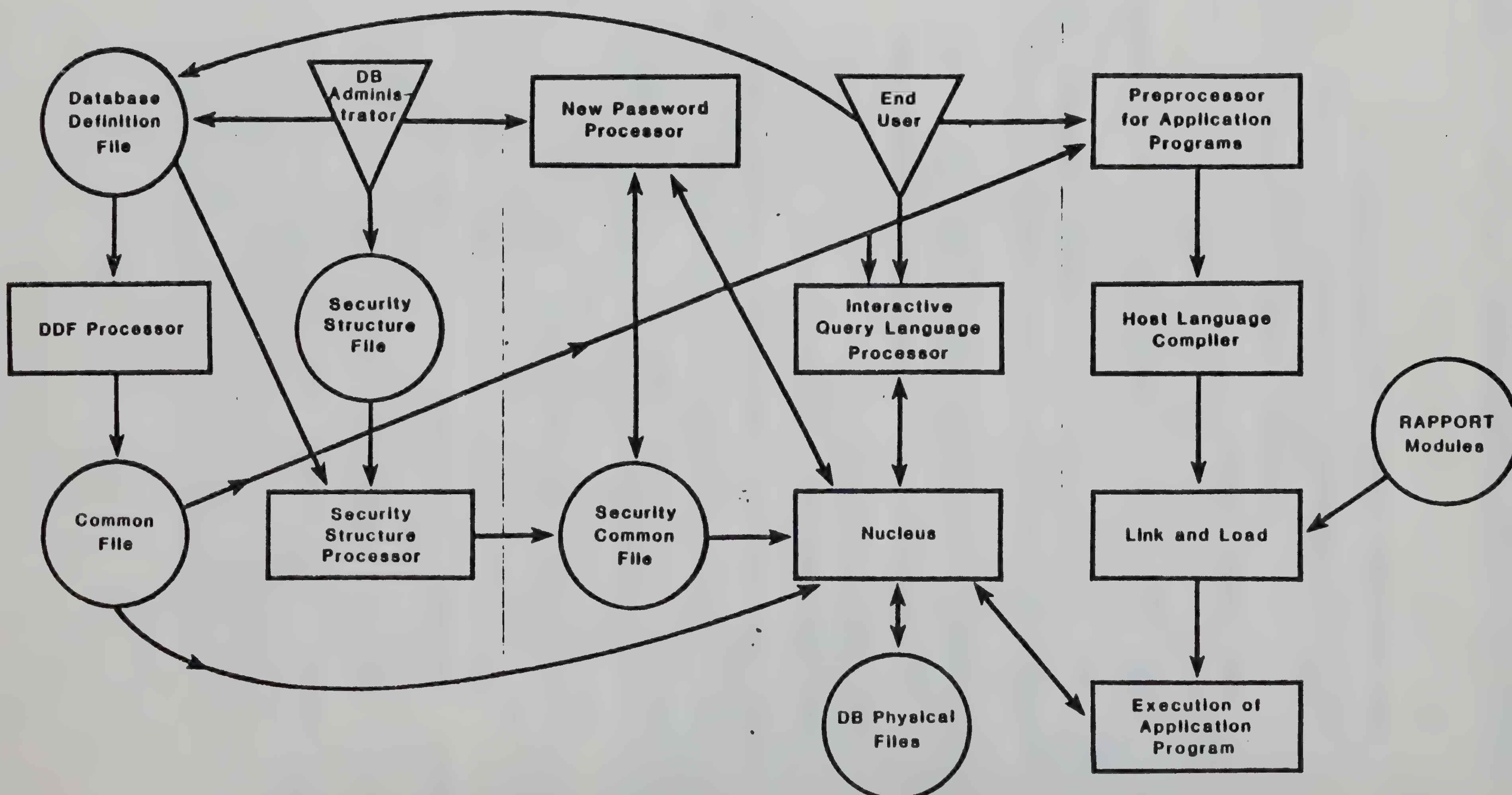
- the log files, the dump files

- the interactions of the Database Administrator with the Nucleus for requesting statistics, backup dumps, logging, recovery, roll-forward operations

- the file in which the Interactive Query Language Processor stores Stored Command Sequences

- the files holding the application program in various forms (source, object, linked).

Sketch of the Overall Architecture of RAPPORT



RAPP

6. Operational Aspects

6.1 Security

Access authorization can be controlled by passwords. Read and read/write authorization are offered.

The individual fields (= attributes) of records and also the subset of records of a file determined by the value of a field can subjected to authorization control.

The system also features a data encryption mechanism. The permission to decrypt and encrypt/decrypt data is controlled by passwords. Prime key attributes and attributes on which secondary indexes are defined cannot be protected by encryption.

Operational aspects :

- The specification of data to be protected by passwords and encryption constitutes the Security Structure File. This file is processed by a utility program (the Security Structure Processor) into data used at run-time by the RAPPORT Nucleus (= database handler) for authorization control and encryption/decryption.

- The Database Administrator can interactively initialize and modify passwords through a utility program (the New Password Processor). Modification of encryption passwords results in the re-encryption of the data concerned (see also Section 5.1).

6.2 Physical Integrity

6.2.1 Concurrency Control

Concurrency control is handled by locking whole files. Two levels of locks are available:

- read locks : the file can be read but not modified by other users;
- write locks : the file cannot be accessed by other users.

Locks are automatically set by the DBMS in a transaction (see Section 3.4.5) as soon as a read or write operation is encountered in the transaction.

Locking of files can be done explicitly at the beginning of a transaction (LOCK statements are provided to that effect).

Deadlocks are detected by the DBMS and are resolved by backing out one of the deadlocked transactions.

Read-only operations can be performed without protection (i.e., without setting locks) outside a transaction.

6.2.2 Crash Recovery

In the case of a single-user access to the database, an application program can create dump copies of the database at checkpoints. In the case of multi-user access to the database, this function can only be performed centrally via a dialogue with the run-time Nucleus of the DBMS.

Before- and after-images of updates can be logged, giving the possibility to recover from a crash up to the most recent transaction completed.

6.3 Operating Environment

6.3.1 Software Environment

RAPPORT is a portable DBMS that can run in an environment which supports FORTRAN and direct access disk I-O. Minimum requirements for the host operating system include a message-passing or shared data mechanism between the run-time DBMS Nucleus and the different user programs.

6.3.2 Hardware Environment

RAPPORT is compact enough to run on small minicomputers, occupying typically 64K bytes at run-time. There is a version for micro-computers requiring only 46K bytes.

7. Essentially Relational Solution for Generalized DBMS Problems

RAPPORT relies on the data structuring tool of the relational model, viz. relations.

Relations appear as flat files in RAPPORT. The operations on these files do not explicitly refer to access paths, thus allowing the modification of these access paths without having to modify the application programs.

This data independence allows a limited form of program performance improvement by mere access paths modifications. RAPPORT does not however follow the "relational ideal" requiring that the formulation of requests to a database be completely separated from efficiency considerations. The RAPPORT data manipulation language is procedural and the requests involving more than one file necessarily embed an access strategy (specifying essentially the order in which the files are accessed). In addition to the modification of data independent access paths mentioned above, performance tuning during the life of a database thus implies the modification of the database access strategies embedded in the application programs.

8. Database Applications Using the System

Existing applications include: computer aided design, industrial process control, scientific data processing, management information systems, financial planning, market research, configuration management, simulation and modelling, exploration data analysis.

Feature Analysis of SYSTEM R

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December 1980

Preface

All examples in this feature analysis are based on the database below:

S#	SNAME	STATUS	CITY
S1	Smith	20	London
S2	Jones	10	Paris
S3	Blake	30	Paris
S4	Clark	20	London
S5	Adams	30	Athens

P#	PNAME	COLOR	WEIGHT
P1	Nut	Red	12
P2	Bolt	Green	17
P3	Screw	Blue	17
P4	Screw	Red	14
P5	Cam	Blue	12
P6	Cog	Red	19

J#	JNAME	CITY
J1	Sorter	Paris
J2	Punch	Rome
J3	Reader	Athens
J4	Console	Athens
J5	Collator	London
J6	Terminal	Oslo
J7	Tape	London

SPJ

S#	P#	J#	QTY
S1	P1	J1	200
S1	P1	J4	700
S2	P3	J1	400
S2	P3	J2	200
S2	P3	J3	200
S2	P3	J4	500
S2	P3	J5	600
S2	P3	J6	400
S2	P3	J7	800
S2	P5	J2	100
S3	P3	J1	200
S3	P4	J2	500
S4	P6	J3	300
S4	P6	J7	300
S5	P2	J2	200
S5	P2	J4	100
S5	P5	J5	500
S5	P5	J7	100
S5	P6	J2	200
S5	P1	J4	1000
S5	P3	J4	1200
S5	P4	J4	800
S5	P5	J4	400
S5	P6	J4	500

From C.J. Date, 1977; An Introduction to Database Systems, Reading, Mass.: Addison-Wesley Publishing Company, pg. 105.

S/R ii

Feature Analysis of SYSTEM R

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Identification

System R is a relational DBMS involving the language SQL (Structured English Query Language). SQL (also called SEQUEL II) is an English-like relational data sublanguage that is the main external interface supported by System R.

Developed by: IBM Research Laboratory
San Jose, California

1.2 Status

1.2.1 System

System R is in current use with implementation of the prototype system now essentially complete, at the IBM Research Laboratory in San Jose, California on an IBM 370. The system is experimental in nature.

1.2.2 Applications

All software for System R was developed as a research tool in relational data base and is not generally available outside of the IBM Research Division.

1.3 System Background

System R is an experimental database management system, based on the relational model, which has been under development at IBM Research Laboratory in San Jose, California since 1975. The prototype system was completed in 1979. System R currently supports the high level relational user sublanguage SQL.

The original version of SQL, called SEQUEL, was based on an earlier

language called SQUARE (Specifying Queries As Relational Expressions). SQL is more English-like than SQUARE. Controlled experiments involving college students were carried out to test SEQUEL's usability. Based on the results of that study, the present SQL was designed. SQL is intended for the non-specialist in data processing as well as the professional programmers and is designed to allow easy definition and access of databases. This is because the user specifies only what is desired, not how to obtain it.

Since SQL's original version, it has been expanded to include a data manipulation facility which permits insertion, deletion, and update of tuples, a data definition facility which allows definition of relations and alternate views of relations and a data control facility which enables each user to authorize other users to access of his data. In addition ,facilities have been added to permit coupling with a high level programming language.

1.4 Overall Philosphy

The developers of System R state the philosphy in the architectural update as follows: "Perhaps the greatest impediment to the use of computerized data management systems is the cost and complexity of understanding and installing such systems. At present, installation of a database management system requires a staff skilled in telecommunication operating systems, data management and in the application area. System R is a relational database management system designed to address this problem. System R is designed to allow easy definition of databases and of the applications which use them while still providing the function and performance available in most commercially available systems."

The goals of System R are as follows (Section 1.7.5):

(a) to provide full capability of DBMS in realistic operating environment.

(b) to provide high level of data independence by isolating end user from underlying storage structure.

(c) to support two different types of processing against database, i.e., ad-hoc queries and updates and canned programs.

(d) to allow easy definition of databases and the applications which use them.

1.5 Essentially Relational Characteristics

System R satisfies all the requirements of a fully relational system, as specified by CODD (TODS Vol. 4, No. 4, Dec. 1979).

1.6 Interfaces

System R contains the SQL user language, contained in the Relational Data Interface (RDI) and the Relational Storage Interface (RSI), an internal interface for accessing tuples in base relations. SQL provides capability for scheme definition, quering, database altering, constraint, definition, database generation, and data entry. RSI supports space management, index and link management, concurrency control and recovery. RSL is not concerned with normal relation operations - further discussion will be made in Section 5.

1.7 Documentation

1. Astrahan, M.M., et. al. System R: Relational Approach to Database Management. ACM Transactions on Database Systems, Vol. 1, No. 2, June 1976, pp. 97-137.

2. Chamberlin, D.D., et. al. Sequel 2: A Unified Approach to Data Definition, Manipulation, and Control. IBM J. Res. Dvlp., Vol. 20, No. 6, Nov. 1976, pp. 560-574.

3. Boyce, Raymond F., Chamberlin, Donald D. Using A Structured English Query Language as A Data Definition Facility. IBM RJ 1318 (#20559) Dec. 10, 1973, pp. 1-15.

4. Chamberlin, D.D., et. al. Data Base System Authorization, IBM RJ 2041 (28513) July 18, 1977, pp. 1-14.

5. Blasgen, M.W., et. al. System R: An Architectural Update. IBM RJ 2581 (33481) July 17, 1979, pp. 1-36.

6. Selinger, P.G., et. al. Access Path Selection in a Relational Data Base Management System. IBM Research Report RJ 2429 Jan. 1979.

7. Chamberlin, D.D., et. al. Support for Repetitive Transactions and Ad-Hoc Query in System R. Research Report RJ 2551, IBM Research Laboratory, San Jose, California, May 1979.

8. Astrahan, M.M., et. al. Evaluation of the System R Access Path Selection Mechanism. IBM Research Report IBM RJ2797 (35713), April 10, 1980.

9. Astrahan, et. al. A History and Evaluation of System R. IBM Research Report RJ2843 (36129), IBM Research Laboratory, San Jose, California, June 12, 1980.

1.8 General System Description

System R adopts a relational data model and supports the language SQL for defining, accessing, and modifying multiple views of stored System R provides the capability for SQL programs to run in two different modes. A user may work with the system interactively using pure SQL commands, or in batch mode by imbedding SQL statements into a PL/I or COBOL program. Programs wirtten in PL/I or COBOL with imbedded SQL statements go through a precompiler, XPREP, in which SQL statements

are replaced by host-language calls to the access module.
The access module is stored in the System R database to protect it from unauthorized modification.
Interactive SQL is supported by a user interface (UFI) which controls dialog management and the formatting of the display terminal. Because the UFI is executing SQL statements that are not known in advance, the access module must be generated dynamically.
Both the UFI and the user's object program are submitted to the Execution-time System (XRDI). The XRDI interacts with the access module security before the database is accessed.
The access module for either batch or interactive mode calls the Research Storage System (RSS). RSS is a special multi-user access method facility for locking, logging, recovery, and index maintenance. RSS performs the actual accessing of the database.

2.0 DATABASE CONSTITUENTS

2.1 General Description

The constituents of the SYSTEM R database are:

DB (= Database)

R (= Table)

V (= View)

T (= Row)

C (= Column)

D (= Domain)

The DB consists of R's of possibly different types. Any one R consists of T's of identical type. A v is an R derived from one or more R's by use of qualifications. A T consists of C values of possibly different type. C's are defined in terms of a D. D's are implicitly defined by the particular C's (column) definition.

2.2 Database

2.2.1 Database Structure

A SYSTEM R database consists of independent snapshots (static derived relations), views (dynamic derived relations) and tables (base relations). In addition, two system tables are maintained for the relations' definition.

2.2.2 Database Operations

A database is defined and generated through the definition and generation of its base and derived relations.

2.2.3 Database Constraints

Nothing found.

2.3 Relation

2.3.1 Relation Structure

The system term for a relation is a table. A relation is perceived as a table of rows and columns. All relations have unique character names. A relation is comprised of tuples of the same type. Duplicate tuples are allowed. A row consists of attributes of possibly different types. Attribute order is insignificant. The name of a table may be qualified by the name of the user who created it. Alias names can be defined using the keyword SYNONYM.

2.3.2 Relation Operations

The basic operation on a SQL relation is the mapping. A mapping returns a collection of values from the key phrase:

```
SELECT  (attribute(s))
FROM    (relation(s))
WHERE   (qualification(s));
```

An omitted attribute list returns all columns of the relation.
An omitted qualification list returns all the rows.
In addition, relations can be created, deleted, linked with another relation, revised by adding columns, modified by inserting or deleting rows, joined. The set operations of union, intersection and difference are supported in SYSTEM R. Relations in these set operations must be union compatible.

2.3.3 Relation Constraints

All relations must be in first normal form. Inter-relational and intra-relational constraints can be made using assertions about the integrity of data in the relation. An assertion is

a SQL predicate which evaluates to TRUE or FALSE. If a modification to a tuple in the relation is issued which violates an assertion, the modification is rejected and a violation code with the names of the violated assertions is returned.

A trigger can be defined to be executed at the occurrence of reading or modification of a tuple of a relaxation. The trigger, which consists of one or more SQL statements, is executed immediately after the read or modification is completed.

2.3.4 Additional Properties Of Relations

Additional attributes can be added to a table via the keyword EXPAND. Tables can be dynamically created and deleted using the keywords CREATE TABLE and DROP TABLE. A row can be uniquely identified by the image command which creates an index for each tuple. A link between two relations which match in the given attribute may be defined.

2.4 Views

2.4.1 View Structure

A user can define both static and dynamic derived relations. The system uses the term and keyword VIEW to define a dynamic derived relation. A view's structure is a portion of an overall relation. A view is dynamically defined by a user as a mapping of an existing relation(s) and views. Each view has a unique character name. Static derived relations are created via the assignment statement. The result of the query is copied

into the database.

2.4.2 View Operations

Once a view has been defined, its operations are the same as those of a table. Queries may be issued against it and other views may be defined in terms of it. However, some modification operations may not be allowed. (Section 2.4.3). Snapshots may be updated, queried or processed in the same way as tables.

2.4.3 View Constraints

Updates may be made via a view only if each tuple of the view is associated with exactly one tuple of a stored relation. An update must not apply a built-in function such as AVG or SUM to a view field which itself is defined by a built-in function (AVG, MAX, MIN, SUM or COUNT); i.e., updates are not permitted for views which involve joining, grouping or duplicate elimination.

2.5 Tuple

2.5.1 Tuple Structure

The system name for tuple is row. System constraints are the only limit on the number of tuples allowed. Attributes differ in a tuple, but different tuples have the same corresponding attributes (and therefore domains). No key is required. A key may be defined by specifying a unique image (index) on a relation. A tuple type, i.e., tuple structure is defined implicitly when a relation is defined.

2.5.2 Tuple Operations

Tuples may be modified via the keyword UPDATE. Single tuples or a set of tuples may be inserted in or deleted from a relation.

Tuples from two relations can be grouped together on pages of memory. This is intended to make access to many-to-one relationships efficient because it limits the number of pages that must be brought into main memory in response to a query.

Links can be used to connect a tuple in one relation to tuples in another relation with the same value in specified attributes.

2.5.3 Tuple Constraints

By using the assertion feature, constraints can be imposed by the user on tuples inserted, deleted or updated within a relation. Examples of this are asserting that values of specified attributes are within a certain range (such as salary), asserting that each employee in a department is also in the payroll roster, and asserting that a new salary is larger than an employee's former salary. If a tuple does not meet the constraint specified in the assertion, the update is not completed and a violation code with error messages are returned.

2.6 Attribute

2.6.1 Attribute Structure

The system term for attribute is column. An attribute's domain is defined at time of relation creation. Attributes are given unique names within their relation. When a relation is defined, the attribute names are specified. Null values are allowed by specifying NULL or NONULL for attributes that

are not part of keys.

2.6.2 Attribute Operations

Attributes can be relationally compared or arithmetically manipulated. The aggregate functions AVG, MAX, MIN, SUM, COUNT are available.

2.6.3 Attribute Constraints

See Section 2.5.3

2.7 Domain

2.7.1 Domain Structure

The system has no term for domain. Domains are implicitly defined when the attributes of a table are declared. Basic data types are character, integer, decimal and floating point.

2.7.2 Domain Operations

Operations defined on domains are string, integer and real comparisons with logical "and", "or" and "not". Domains are the basis of compatibility of relation element components. Arithmetic operations (add, subtract, multiply, divide) are defined on integers and reals with set functions (AVG, MAX, MIN, SUM and COUNT) defined on appropriate domains.

2.7.3 Domain Constraints

Nothing found.

2.8 Additional Database Constituents

SQL allows a group of modifications to be placed in a transaction block, using BEGIN TRANSACTION

.

.

.

END TRANSACTION

A trigger can be defined to be executed at the occurrence of some modification of a tuple. The trigger is executed immediatetly after the tuple update is completed.

Assertions are supported by SYSTEM R. To users with control privileges on a table (e.g. a DBA) when an assertion is issued, the system static assertions can be made about individual tuples in a relation or about one or more relations. Transistion assertions are enforced either upon completion of a statement or upon completion of a transaction.

3.0 FUNCTIONAL CAPABILITIES

3.1 Qualification

SQL mappings are used for n-element selection on the basis of a mapping. In general, a mapping returns a collection of values, i.e., the selected attributes of the tuples that satisfy the WHERE clause.

An example of qualification for an attribute through the WHERE clause:

```
SELECT  * (* is SYMBOL for all)
FROM    S (RELATION)
WHERE     CITY = 'LONDON';
```

Duplicate values are not eliminated from the returned set unless the user requests unique values. The result of a query is returned in system-determined order unless the user requests an ordering. The result of a query is a relation.

3.1.1 Restriction

All operators (< ,>, ≤, ≥,=,≠)can be used in the qualification. The qualification may appear as a constant, another attribute or another nested query (SELECT). Boolean expressions can be composed using AND, OR and NOT can be included.

The truth value of the WHERE clause is computed using two-valued logic to evaluate ANDs and ORs. The tuple is considered to satisfy the WHERE clause if the overall truth value of the clause is TRUE but not if the overall truth value is FALSE. An exception to the above rules is made in the case of predicates that search for null values explicitly. In these predicates, the null value is treated like any other value.

The projection command is represented by a vertical subsetting. Again, duplicate tuples are only eliminated if the user so specifies. The SQL projection command has no WHERE clause. Essentially, all tuples are selected.

3.1.2 Quantification

Not supported.

3.1.3 Set Operations

System R supports the set operations INTERSECT, UNION and MINUS. The following is an example of set difference return suppliers supplying no parts:

```
SELECT  S#
FROM    S
MINUS
SELECT  S#
FROM    SP;
```

A query may contain several set theoretic operations, with parentheses used as needed to resolve ambiguities. Duplicate tuples are eliminated from the operands before performing the set operation. A special built-in function called SET is provided that evaluates a set of values for a particular attribute which is present in a given group. This set of attributes may then be compared with other sets. Set equality, set inequality, set inclusion and set non-inclusion operations exist in the SQL language.

3.1.4 Joining

SQL supports the join operation. Joins can be made over several relations as well as over one relation. The user must be careful in multiple relation joins to properly qualify each attribute name. Conceptually, the Cartesian product of these relations is formed

and then filtered by the predicates in the WHERE clause. Both the equi-joins and the natural join are available.

```
SELECT  S#,P#
FROM    S,P
WHERE   S.CITY = P. CITY ;
```

3.1.5 Nesting and Closure

A predicate in a WHERE clause may test an attribute for inclusion in a set. It is possible to use the result of a mapping in the WHERE clause of another mapping. This is called nested mapping. Multiple levels of nesting are allowed in qualifications. The inner mapping of a nested retrieval is performed first, then the outer mapping uses the results of the inner mapping as a set of constants.

For example:

Find part number of all parts supplied by more than one supplier:

```
SELECT P#
FROM   SP, SPX
WHERE  P# IN (IN is equivalent to = )
       SELECT P#
       FROM   SP
       WHERE  SP.S#>  = SPX.S#;
```

3.1.6 Additional Aspects of Qualification

None found.

3.2 Retrieval and Representation

3.2.1 Database Queries

A query block is represented by a SELECT list, a FROM list and a WHERE tree containing the list of items to be retrieved, the table referenced

and the Boolean combination of simple predicates specified by the user. A single SQL statement may have many query blocks because a predicate may have one operand which is itself a query.

3.2.2 Retrieval of Information about Database Constituents

System R automatically maintains catalogs that describe all tables, views, images, links, assertions, and triggers that are known to the system. These catalogs are kept in the form of tables which may be queried in the same way as any other table. Each catalog entry has space for a comment which may be filled in by the creator of the relevant object.

3.2.3 Retrieval of System Performance Data

The operating system schedules periodic checkpoints and maintenance usage and performance statistics for reorganization and accounting purposes.

3.2.4 Report Generation

The SQL select clause can be used to generate output in report form. Uniqueness of tuples can be specified by the keyword UNIQUE. The GROUPED BY clause can be used to select tuples satisfying a unique property of a group. A predicate in a HAVING clause may compare an aggregate property of the group to a constant or to another aggregate property of the same group. The ORDER BY clause will sort on a specific attribute.

3.2.5 Constraints and Limitations

When a user queries a relation, a security check is made as to whether he has access to the relation involved before any operation is done.

Views can be used to accomodate queries into certain sections of a relation in which other information is privileged.

3.2.6 Additional Aspects of Retrieval and Presentation

Data can be retrieved for the purpose of insertion into other relations and updates in other relations.

3.3 Alteration

3.3.1 Insert Facilities

Relations and views can be altered by insertion. A relation or view can be added by inserting one tuple or a set of tuples. Attributes not given values in the insertion assume null values.

For example:

```
INSERT INTO P: <'P7', 'WASHER', 'GREY', 2, 'ATHENS'>;
```

A query result can be used as a table for insertion in another relation.

For example:

```
INSERT INTO   P:
SELECT        *
FROM          W
WHERE         COLOR = 'RED';
```

3.3.2 Delete Facilities

Deletion alters relations and views by removing a row or rows satisfying some condition. Rows are specified by a WHERE clause syntactically identical to a query WHERE clause.

For example:

```
DELETE S
WHERE  S#=
       SELECT *
       FROM   W
       WHERE  STATUS=20;
```

3.3.3 Modify Facilities

Updates can be used to alter rows in a relation by changing specific data values. As in the DELETE and INSERT facilities, the parameter in the WHERE clause is considered a table in itself. An update is similar to delete except the SET clause is used to specify the updates to be made.

For example:

Change the color of P2 to yellow

```
UPDATE P
SET COLOR = 'YELLOW'
WHERE P# = 'P2';
```

For example:

Increase QHO by 10% if they are in the W table.

```
UPDATE P
SET    QHO = QHO*1.1
WHERE  P1 IN
       SELECT *
       FROM W ;
```

3.3.4 Commit and Undo Facilities

A transaction recovery scheme is provided which allows a transaction to be backed out to the beginning of the transaction. Transaction recovery occurs when the RESTORE_TRANSACTION is issued. The effect is to undo all changes made by that transaction. See Section 3.4.5.

3.3.5 Additional Alteration Facilities

No additional features found.

3.4 Additional Functional Capabilities

3.4.1 Arithmetic and String Operations

Simple addition, subtraction, multiplication and division are supported in qualifications and update functions. A user may construct arithmetic operations in the SELECT clause.

3.4.2 Sorting

A user may specify a query to be presented in ascending or descending order using the keywords ORDER BY

For example:

```
SELECT      S#,SNAME          (GIVES NAME AND NUMBER
FROM        S                  OF SUPPLIERS IN LONDON
WHERE       CITY = 'LONDON'    ALPHABETIZED BY SUPPLIERS'
ORDER BY    SNAME;             NAMES)
```

3.4.3 Library Functions

The functions AVG, MAX, MIN, SUM and COUNT are supported and can be used in queries.

For example:

```
SELECT AVG (QTY)              (GIVES AVERAGE QUANTITY
FROM   SP                      OF S1'S PARTS)
WHERE  S# = "S1";
```

3.4.4 User Defined Functions

System R allows a user to add additional functions to the system by placing routines written in SQL and, say PL/I, in a special function library.

3.4.5 Transactions

The system permits a series of alterations to be placed in a transaction block, with the statements inside to be executed as an atomic operation without interference by other users. A three leveled locking technique can be used to handle various concurrency problems.

For example:

```
BEGIN TRANSACTION
        .
        .
        .
END TRANSACTION ;
```

3.4.6 Multi-Tuple Alterations

See Sections 3.3.1,.3.3.2 and 3.3.3.

3.4.7 Grouping

A relation can be partitioned into groups according to values of some attribute. Then a built-in function may be applied to each group. Each item in the SELECT clause must be a unique property of a group instead of a tuple.

For example:

```
SELECT   P#,(COUNT(S#)
FROM     SP
GROUP BY P#;
```

All set functions AVG, MAX, MIN, SUM and COUNT can be used in this manner.

3.4.8 Exception Handling Mechanisms

Error Messages and codes are returned for invalid SQL commands and access violations.

3.4.9 Additional Functional Capabilities

None.

4.0 DEFINITION, GENERATION AND ADMINISTRATION FACILITIES

4.1 Definition Facilities

4.1.1 Constituents of a Database Definition

A database is defined through the definition of relations or table, view, tuple (row), column, (attribute). Views are thought of as derived relations, and rows and columns are used for base and derived relations. Access paths are maintained by the system.

4.1.2 Database Definition

A database is defined through the definition of relations (base and derived). There is no known limit to the number of relations allowed.

4.1.3 Relation Definition

A relation is defined through the keywords CREATE TABLE:

For example:

```
CREATE TABLE   X
STATUS DECIMAL (4)
SNAME  CHARACTER (20)
CITY   CHARACTER (40);
```

There is no known restriction on the number of rows or columns.

A static derived relation can be defined by:

For example:

```
ASSIGN TO X       (SNAME, STATUS, CITY)
          SELECT  SNAME, STATUS, CITY
          FROM    S;
```

The command KEEP TABLE (table-name) causes a temporary table (such as one made through the ASSIGN clause) to become permanent. A relation can be deleted by the DROP TABLE command.

4.1.4 View Definition

Views can be created and dropped dynamically. Dynamic derived relations are defined by the example:

```
DEFINE VIEW V60 AS
        SELECT    S#,SNAME
        FROM      S
        WHERE     S#>'S1';
```

A view is not stored physically. It is a dynamic windown on a data base.

4.1.5 Tuple Definition

Tuples are implicitly defined when tables are defined.

4.1.6 Attribute Definition

Attributes are defined when tables are defined.

4.1.7 Domain Definition

Domains are defined within attributes.

4.1.8 Definition of Additional Database Constituents

A user may define a TRIGGER to be executed upon the occurrence of a specified action (READ, INSERTION, DELETION or UPDATE). An example of a TRIGGER definition is:

```
DEFINE TRIGGER  T1
 ON UPDATE OF S(S#)
   (UPDATE SP
    SET S# = NEW.S#);

    UPDATE S
    SET S# = 'S6'
    WHERE S# = 'S1';
```

When a supplier's number is changed in relation S, make the same change in its derived relation SP.

Trigger can be deleted via the DROP TRIGGER command.

Assertions can be defined by: (See Section 2.8)

```
ASSERT N ON SP:<QTY 10,000 >;
```

4.2 Generation Facilities

4.2.1 Constituents of Database Generation

The database is generated by populating the relations of the database. Insertion commands both through SQL or a high-level language may be used for the population.

4.2.2 Generation of Database Constituents

Base relations may be populated by the insert command. Static derived relations are populated automatically. Dynamic derived relations use access paths to indicate what tuples are to be included in the generation.

4.3 Data Base Redefinition

4.3.1 Renaming Database Constituents

Aliases are allowed using the keyword SYNONYM. Nothing found on renaming.

4.3.2 Redefining Database Constituents

Relations and tuples can be redefined by the addition of attributes via the EXPAND command. There is no known limit on the addition of attributes. Indexes on tables can be added and destroyed.

4.4 Database Regeneration and Reorganization

4.4.1 System - Controlled

The RSS permits new stored tables or new indexes to be created at any time, or existing ones destroyed without dumping and reloading the data. New fields can be added. Add or delete pointer chains across existing tables can be defined at any time.

4.4.2 DBA - Controlled

A table or other object may be dropped or authorized for use only by the user who created it. User-ids have, therefore, been used to represent the role of the DBA and not specific persons. The DBA can created, control and destroy those portions of the database which he has created. Private users can create relations for their own private use. All the query facilities are available to the DBA. Private users have certain authorization restrictions as determined by the DBA.

4.5 Database Dictionary

SQL is an integrated data definition and data manipulation language. In System R the description of the database is stored in user visible 'system' tables which may be read using the SQL language. The creation

of a table or an access path results in new entries in these system tables. Users defining tables and other objects are encouraged to include English text which describes the 'meanings' of the objects. Later, others may retrieve all tables with certain attributes or may browse among the descriptions of defined tables (if they are so authorized).

5.0 INTERFACES AND DBMS ARCHITECTURE

5.1 System Architecture

System R architecture is divided into two subsystems, Relational Data System (RDS) and Research Storage System (RSS).

The Relation Data Interface (RDI) is the external interface of System R which can be called directly from a programming language. SQL is embedded within the RDI.

RSI (Relation Storage System) is an internal interface which handles access to single tuples of base relations.

5.2 Interface Descriptions

5.2.1 SQL Description

SQL is a non-procedural, mapping oriented relational language. SQL is English-like free-format narrative. SQL can either stand alone or can be embedded in COBOL or PL/I. SQL statements are prefixed by $-signs when embedded. SQL has been implemented as a stand alone interactive language or as an embedded batch-oriented language.

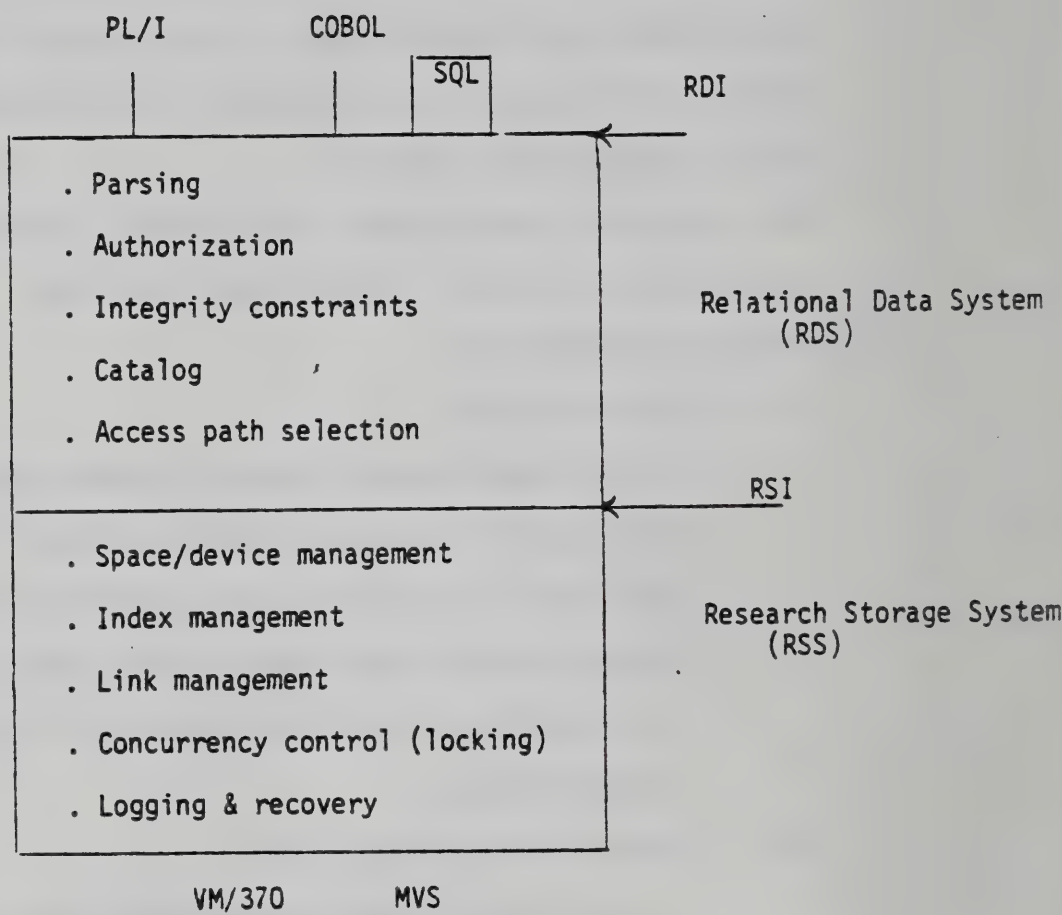
5.2.2 Research Storage System (RSS)

The interfaces to these two subsystems are called:

Relational Data Interface (RDI)

Relational Storage Interface (RSI)

The architecture of System R is shown on the following page. Some of the subsystems are shown.



5.2.2.1 RDI Operators

The RDI (Relational Data Interface) is the external interface of System R which can be called directly from a programming language. SQL is embedded within the RDI. System R uses the following RDI operators: SEQUEL, FETCH, FETCH_HOLD, OPEN, CLOSE, KEEP, DESCRIBE, BIND, BEGIN_TRANS, END_TRANS, SAVE, RESTORE and RELEASE.

SQL statements embedded in PL/I programs and host-language variables appearing in those statements are prefixed with $-signs as shown below:

```
$UPDATE PARTS
 SET    PNAME=$X
 WHERE  STATUS=$Y;
```

An INTO clause delivers the query result to the host program. For example:

```
$SELECT PNAME, STATUS
 INTO   $X, $Y
 FROM   P
 WHERE  P#=$Z;
```

This returns only the first tuple in the query result. To process more than one tuple, a cursor is required. A cursor is a symbolic name associated with a query for the purpose of retrieving a query result, tuple by tuple. In the following example, PARTS is the symbolic or cursor name:

```
$LET PARTS BE
 SELECT PNAME, STATUS
 INTO   $X, $Y
 FROM   P
 WHERE  P#=$Z;
```

The OPEN statement binds the value of the input variable and prepares to deliver tuples in accordance to the query. The FETCH clause causes a new tuple to be delivered into the

program value specified by the query. The CLOSE statement informs the system that no further fetches will be issued by the query:

```
$OPEN PARTS;
$FETCH PARTS;
$CLOSE PARTS;
```

After the execution of each SQL statement, a status code is returned to the host program in a variable called SYR_CODE. The FETCH statement can be used in conjunction with the status code to process all tuples of a given relation.

```
DO WHILE(SYR_CODE=OK);
 $FETCH PARTS;
 PUT SKIP LIST $X, $Y;
END;
```

The DESCRIBE statement returns a description of the number of fields and data types of the result into an array indicated in the query. SQL statements may be dynamically defined by the PREPARE statement. The PREPARE statement indicates to System R that, at run time, the character type variable specified will contain a SQL statement which should be optimized and associated with the appropriate name. Unknown parameters are indicated by question marks. To execute the prepared command, the EXECUTE command is issued. All statements not beginning with SELECT are handled by means of the EXECUTE command.

5.2.2.2 RSI OPERATORS

RSI (Relational Storage Interface) is an internal interface which handles access to single tuples of base relations. All data is stored in a collection of logical address spaces called segments. The OPEN_SEGMENT operator makes a segment available for processing. When the SAVE_SEGMENT command is issued, disk pages bound to segments are brought up-to-date. The RESTORE_SEGMENT command restores the original segment value. CLOSE_SEGMENT commands make the segment unavailable for further processing. Records can be fetched across a particular access path through the OPEN_SCAN command. The records can then be accessed by a sequence of NEXT commands.

A user may determine which records will be children of a given parent. The relative order of the children under a given parent can be determined by the CONNECT and DISCONNECT operations. Lock operations provide concurrency protection of relations and segments within relations.

6.0 OPERATING ASPECTS

6.1 Security

6.1.1 Access Control

When a SQL statement is translated and the access path chosen for the operation in question, a check is made to see if the user involved is authorized to operate on the relation. Log-on authorization is performed by the virtual memory monitor. a user can control access to the data objects the user creates by use of the GRANT and REVOKE operations.

```
GRANT [auth] table-name to user-list
      [WITH GRANT OPTION];
REVOKE [operation-list ON]  table-name
      FROM user-list;
```

6.1.2 Capability

A user has the capability of granting to or revoking from other uses the following privileges regarding relations he has created: READ, INSERT, DELETE, UPDATE (by column), EXPAND, IMAGE (to define images on the relation), LINK (to create links on the relation), CONTROL (to make assertions or define triggers pertaining to the relation) and GRANT (grant the right to grant). [8]

6.2 Physical Integrity

6.2.1 Concurrency Control

System R permits multiple users to be active simultaneously, performing a variety of activities. These simultaneous activities are supported by the automatic locking subsystem built into the RSS.

The transaction mechanism allows a user to keep his view of the database constant throughout his operations, ignoring other user requests.

System R provides the user with a choice of three levels of locking. Level 3, to which the system defaults, provides the most complete protection by allowing one user to complete a transaction without intervention from another user. For example, data read by a user cannot be updated by another user until the first user has terminated. Level 2 and Level 1 provide locking at a lower degree. Level 1 allows other users to read data that is currently being updated. Level 2 also allows other user to read data that is currently being updated, however, Level 2 locks each record before reading it to make sure it is committed at the time of the read. The lock is released immediately after the read has been completed.

6.2.2 Crash Recovery

System R has complete facilities for transaction backout and system recovery. Recovery compensates for system failures of the magnetic media (Disk Head Crash). Almost all recovery information is kept on disk and a non-catastrophic restart is transparent to operations.

6.3 Operating Environment

6.3.1 Software (Operating System)

System R requires the VM/370 operating system for best operation. IBM reference manuals describe the system in detail.

6.3.2 Hardware

System R has been implemented on Virtual Machine/370, an IBM System/370. The system requires at least one direct access storage device.

The system requires storage on any 370 Direct Access Device (e.g., IBM's 3330 Disk Drive). Magnetic tape is required for backup to support audits and database reconstruction after system failure.

System R can handle multiple users concurrently accessing the database. Any System/370 compatible terminal may be utilized. System R can operate on any IBM 370 with dynamic address translation capability.

7.0 ESSENTIALLY RELATIONAL SOLUTIONS FOR GENERALIZED DBMS PROBLEMS

System R incorporates the following claimed advantages of the Relational Approach:

Simplicity - System R has only one major structure, the table, and operations for manipulation of the table.

Uniformity - System R queries exhibit closure.

Data Independence - Ordering and indices are strictly optional, while access paths are transparent to users. SQL is a non-procedural language.

Permits optimization - Each data access path is found after an optimization routine is used.

Interfaces are high level.

Multiple views are supported.

8.0 DATABASE APPLICATIONS USING THE SYSTEM

System R was evaluated by IBM for approximately two and one-half years. The results of this evaluation can be found in "A History and Evaluation of System R", RJ2843 (36129), IBM Research Laboratory, San Jose, California 95193. The evaluation consisted of two parts: (1) experiments performed on the system at the San Jose Research Laboratory and (2) actual use of the system at a number of internal IBM sites and three selected customers. The typical experimental databases were smaller than 200 Megabytes with less than ten concurrent users. A summary of their results follows:

1) Several user sites were able to install System R, design and load a database, and run application programs in a matter of days.
2) Indexes could be created and dropped without impacting users or application programs.
3) Joins on several tables degraded performance.
4) The users felt that the SQL language was easy to learn. Users with no experience were able to learn a subset of the language in one sitting. SQL was judged generally successful in meeting its design goals.
5) All SQL statements were reduced to machine code by selecting code fragments from a library of approximately one-hundred fragments. In a typical short transaction of less than 50,000 instructions, 80% of the instructions were executed by the RSS access module. The remaining 20% were executed using the

access module and the application program. Code generation adds a small amount of CPU time and no I/O time. If this results in a routine which runs more efficiently, the cost of code generation is paid back after a few record fetches.

6) A B-tree index was used to represent access paths. This proved to be appropriate for programs with many record accesses, but was not cost-efficient when only a few resources were accessed.

7) View definition and controlling authorization was found to be powerful, flexible and convenient. User suggestions included developing the concept of group users, implementing a command which changed ownership and optionally saving views and authorization when base relations are dropped.

8) Experimentation has shown that a "Write-Ahead Log" protocol is superior to the "Shadow-Box" protocol for the System R recovery system.

9) It was found that most users ran under the Level 3 option of the security system. In fact, the Level 2 option proved to be more expensive than Level 3.

10) It was found that, in a small number of cases, a query could hold a lock when its time slice ended, thus holding up other queries until it received another time slice. The lock release protocol was changed to correct this.

ADDENDUM TO 1.2.1 SYSTEM

The documents in the public domain concerning System R are not consistent with the implementation of System R, release 4.0. The following is a list of the inconsistencies with the Section in which they appear.

	Item	Explanation	Section
1.	Links	not implemented	2.3.2, 2.3.4, 2.5.2, 3.2.2, 4.4.1, 6.2.2
2.	Set operators	not implemented	2.3.2, 3.1.3, 3.3.3
3.	Assertions	not implemented	2.3.3, 2.4.3, 2.5.3, 2.8, 3.2.2, 4.1.8, 6.2.2
4.	Triggers	not implemented	2.3.3, 2.8, 3.2.2, 4.1.8, 6.2.2
5.	Natural join	System R will not perform an equi-join on common attribute names without those names being specified in the WHERE clause	3.1.4
6.	Nonequi-joins	System R will perform nonequi-joins, but it will not optimize them	3.1.4
7.	User defined functions	not implemented	3.4.4
8.	DECIMAL	not on implemented data type	4.1.2
9.	ASSIGN TO	not implemented	4.1.2
10.	KEEP TABLE	not implemented	4.1.2

11.	RDI operators	the System R host language interface uses a precompiler which translates SQL statements into the appropriate RDI calls. Therefore, the applications programmer codes SQL instead of the listed RDI operators	5.2.2.1
12.	IMAGE	the syntax to create an index is CREATE INDEX	6.2.2
13.	Operating system	System R was also implemented on MVS	6.3.1
14.	Domains	System R does not support the domain constituent	2.1, 2.6.1, 2.7.2 4.1.7
15.	View definition	A more correct definition is: A view may be defined to be the result of any SQL statement.	2.4.1
16.	Key definition	A more correct definition is: unique index and specifying the "NO NULL" option for each column of the index in the CREATE TABLE statement	2.5.1

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This is Volume II of the Final Report of the Relational Task Group (RTG), a task group of the American National Standards Institute (ANSI) subordinate to the ANSI/X3/SPARC Data Base Systems Study Group (DBSSG) currently chaired by W. Terry Hardgrave of the Institute for Computer Sciences and Technology of the National Bureau of Standards.

In May 1979, the RTG was chartered to investigate Relational Database Management Systems and to propose a standards project if appropriate. The RTG produced a final report (NBS-GCR-82-379) plus this supplemental material and a proposal for a relational DBMS standards project. This report describes the features of current relational systems and provided the groundwork for the RTG conclusions. NBS submitted both volumes of the RTG report to NTIS in order to make them publicly available.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

American National Standards Institute; computer standards; DBMS; database management; database standards; Data Base System Study Group; query language; relation; relational model; Relational Task Group

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